Endocrine Disruptors and Pharmaceuticals Strategic Initiative Expert Workshop Report

Project #4124
Subject Area: High-Quality Water

October 2-3, 2007 • Marina del Rey, California
CONTENTS

EXECUTIVE SUMMARY ................................................................. iii

STRATEGIC INITIATIVE OBJECTIVES ................................................. 1

PROJECT SCOPE AND DESCRIPTION .............................................. 1

TASK 1. DEVELOPMENT OF LITERATURE REVIEW ............................ 2

TASK 2. EXPERT WORKSHOP ........................................................ 2

APPENDIX A – LITERATURE REVIEW

APPENDIX B – EXPERT WORKSHOP MATERIALS

• Agenda

• Introductory Presentations

APPENDIX C – PROJECT ABSTRACTS
EXECUTIVE SUMMARY

The Awwa Research Foundation (AwwaRF) has endorsed the Endocrine Disrupting Chemicals (EDCs) and Pharmaceuticals and Personal Care Products (PPCPs) Strategic Initiative (SI) to develop a multi-year research plan to address pressing needs in the EDC and PPCP drinking water research arena. The research plan will identify and prioritize projects that will materially further our knowledge of these potential drinking water contaminants.

This workshop report, which prepares important input for this SI, was developed through the execution of the following two tasks:

1. Development of a white paper to summarize the state of science and research needs
2. Conducting an Expert Workshop Getting to solicit research ideas from water industry experts

Project ideas were solicited in advance of the workshop through a project website. The suggested projects were presented at the workshop and discussed by the participants working in groups. The participants consolidated projects, added new projects and expanded on pre-submitted project descriptions. In addition, they developed or vetted preliminary funding levels and estimated project timelines. The projects were finally ranked based on the following criteria:

- Fills critical information needs in the EDC/PPCP research arena
- Likelihood for success in the project

The projects were also voted on by all workshop participants, and a top-voted project was identified from each of the five focus areas – toxicology and health effects, source water protection and occurrence, methods, treatment, and customer outreach and regulatory.
STRATEGIC INITIATIVE OBJECTIVES

In January 2007, the AwwaRF Board of Trustees directed AwwaRF to undertake a new program of strategic research initiatives. The strategic initiative (SI) program is initiated to effectively sustain multi-year, multi-project research initiatives aimed at solving a particular problem: one of these strategic topics being EDCs/PPCPs. The vision statement for the strategic initiative is:

AwwaRF, in collaboration with regulatory agencies and other stakeholders, will lead a comprehensive research effort to better understand the occurrence, fate, human health significance, and control of EDCs and PPCPs in drinking water. This coordinated research effort will foster consensus among drinking water supply professionals and regulators on appropriate actions required to protect human health by providing the following specific outcomes:

- Development of reliable, cost-effective methods to detect and quantify PPCPs, EDCs, or endocrine disrupting activity in drinking water
- Assessment of the occurrence of these compounds
- Evaluation of the toxicological relevance to human health
- Cost effective source control and drinking water treatment alternatives
- Effective tools and strategies for outreach and communication with drinking water customers

There will be a number of differences between the projects initiated under the SI and standard AwwaRF projects. First, the projects funded under the SI must all relate to the goals defined for the SI while “advancing the science of water”, which is the standard goal applied to all AwwaRF projects. Second, these projects’ goals must meet the SI’s goals and be clearly stated, defined, and their progress must be measurable. Finally, these projects will be identified by an Expert Panel, which members are stewards of the initiative and will assist AwwaRF in continuity and focus of the SI. This expert panel will incorporate advances in knowledge from AwwaRF and other research activities as well as industry needs, as they select new projects to begin each year.

PROJECT SCOPE AND DESCRIPTION

AwwaRF contracted Malcolm Pirnie in March 2007 to facilitate and document an expert workshop which would provide input into the research planning for this SI. AwwaRF then formed an Expert Panel to provide guidance and oversight for the projects to be developed under this initiative. The members of this Expert Panel represented water utilities, consulting firms, and academia, and are listed below:

- Shane Snyder, PhD – Southern Nevada Water Authority
- Alan Roberson, PE – AWWA Government Affairs Office
- Phillippe Daniel, PhD, PE – Camp Dresser & McKee, Inc.
- Paul Westerhoff, PhD, PE – Arizona State University
This project was conducted through the execution of primarily two tasks. This report summarizes the execution and outcome of the two tasks:

TASK 1. DEVELOPMENT OF LITERATURE REVIEW

A Literature Review (see Appendix A) was prepared to provide background information on the state of science both for the Expert Workshop (Task 2, below) and for establishing preliminary research needs. Sources for the Literature Review included previously published AwwaRF reports, EPA report, and peer-reviewed journal publications. The Literature Review was reviewed and commented by members of the Expert Panel, and comments were incorporated in the final version of the document. Based on review of the available literature, the Literature Review identified research needs in five primary focus areas:

- Toxicology and health effects
- Source water protection and occurrence
- Methods
- Treatment
- Customer outreach & regulatory

TASK 2. EXPERT WORKSHOP

On October 2-3, 2007, an Expert Workshop was held at Marina del Rey, California to get input from water industry experts on the development of suggested research projects for this SI. The workshop attendees included water utility, consulting, university, USEPA, and AwwaRF staff. The workshop was facilitated by Mr. Ed Means of Malcolm Pirnie.

Prior to the workshop, the participants were requested to submit brief abstracts containing their research ideas. 41 abstracts were received from the participants prior to the workshop. The abstracts were categorized into five focus areas that were identified by the Literature Review (Task 1, above). At the workshop, the attendees joined break-out groups which were formed based on the focus areas and further developed the project ideas.

The breakout groups were tasked to develop projects that would have the following features:

- Fills critical information needs in the EDC/ PPCP research arena
- A high likelihood for success in the project

Based on this guidance, the breakout groups developed 28 project ideas along with their objectives. For each project, a brief description of background, objectives, project approach, recommended budget, schedule, and potential research partners were identified.
The sub-groups reported summary descriptions of their projects to the entire group. These ideas then were voted on by the participants in two different ways:

- Five projects that fill a critical need and have a high likelihood of success
- One project in each focus area that fills a critical need and has a high likelihood of success

The total votes received by the projects in both categories, including the focus area categories, estimated budget and schedule, and ranking are shown in Table 1. The top-voted project from each of the five focus areas are presented in Table 2. Additional details on the workshop including agenda, list of attendees, and introductory presentations made by Malcolm Pirnie staff are included in Appendix B. Detailed abstracts of all projects developed at the workshop including project objectives and approaches are included in Appendix C.
<table>
<thead>
<tr>
<th>Abstract #</th>
<th>Project ID #</th>
<th>Focus Area</th>
<th>Project Title</th>
<th>Fill Critical Info Need *(1 High, 3 Low)</th>
<th>Likelihood for Success *(1 High, 3 Low)</th>
<th>Estimated Budget ($)</th>
<th>Estimated Project Timeline (Boxes in Red Indicate the Duration of the Project)</th>
<th>One Per Category</th>
<th>5 Favorites</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4-34-43</td>
<td>Toxicology and Health Effects</td>
<td>Handbook of Screening Values for Unregulated Contaminants such as EDC, Pharmaceuticals, and PCP Ingredients</td>
<td>1</td>
<td>1</td>
<td>400,000</td>
<td>2008 2009 2010 2011 2012</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>Customer Outreach &amp; Regulatory</td>
<td>Interim Water Utility Strategy Plan for Responding to Emerging Contaminants Challenges</td>
<td>1</td>
<td>1</td>
<td>150,000</td>
<td></td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>37</td>
<td>Treatment</td>
<td>Transformation of pharmaceutically-active compounds (PhACs) by chemical disinfectants to toxic or odoriferous products</td>
<td>1</td>
<td></td>
<td>325,000</td>
<td>2008 2009 2010 2011 2012</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Treatment</td>
<td>Assessment of Quantitative Structure Property Relationships (QSPR) Techniques to Predict Removal of EDC/PPCPs in Drinking Water Treatment</td>
<td>1</td>
<td></td>
<td>625,000</td>
<td>2008 2009 2010 2011 2012</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>27</td>
<td>11-16-22-24-31</td>
<td>Methods</td>
<td>Method Validation by Inter-laboratory Comparison for Priority Pharmaceuticals (GWRC)</td>
<td>1</td>
<td></td>
<td>750,000</td>
<td>2008 2009 2010 2011 2012</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>18</td>
<td>2-8-12</td>
<td>Source Water Protection and Occurrence</td>
<td>Characterization of Source Water Quality, Finished Water Quality, and Treatment Process Effectiveness Related to EDCs and PPCPs</td>
<td>2</td>
<td>2</td>
<td>533,000</td>
<td></td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Abstract #</td>
<td>Project ID #</td>
<td>Focus Area</td>
<td>Project Title</td>
<td>Fills Critical Info Need <em>(1 High, 3 Low)</em></td>
<td>Likelihood for Success <em>(1 High, 3 Low)</em></td>
<td>Estimated Budget ($)</td>
<td>Estimated Project Timeline (Boxes in Red Indicate the Duration of the Project)</td>
<td>One Per Category</td>
<td>5 Favorites</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>------------------------------------------</td>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>13</td>
<td>38</td>
<td>Treatment</td>
<td>Natural Attenuation of EDC/PPCPs in Surface Waters (as part of a multiple barrier approach) Removal of PhACs in Engineered Treatment Wetlands</td>
<td>1</td>
<td>1</td>
<td>450,000</td>
<td>check on start</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>Customer Outreach &amp; Regulatory</td>
<td>Information Database for Compounds of Potential Concern (follows GWRC project and #4)</td>
<td>1</td>
<td>1</td>
<td>150,000</td>
<td></td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>17</td>
<td>3-10-14</td>
<td>Source Water Protection and Occurrence</td>
<td>Occurrence, Fate and Transport of EDCs and PPCPs in Surface Water - Representative Case Studies</td>
<td>1</td>
<td>1</td>
<td>600,000</td>
<td></td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>19</td>
<td>32B</td>
<td>Source Water Protection and Occurrence</td>
<td>Developing Source Water Protection Strategies for Addressing EDCs and PPCPs</td>
<td>1</td>
<td>1</td>
<td>350,000</td>
<td></td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>5-32A-39</td>
<td>Source Water Protection and Occurrence</td>
<td>Contributions of EDCs and PPCPs to Drinking Water Sources From Point and Non-Point Input other than Wastewater Treatment Effluents</td>
<td>1</td>
<td>2</td>
<td>1,000,000</td>
<td></td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>26</td>
<td>46</td>
<td>Toxicology and Health Effects</td>
<td>Computational Toxicology - CRADA</td>
<td>2</td>
<td>1</td>
<td>100,000</td>
<td></td>
<td>As Required</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>15-19</td>
<td>Toxicology and Health Effects</td>
<td>Linking Validating Bioassays of Exposure, Effects, &amp; Public Perception</td>
<td>2</td>
<td>1</td>
<td>400,000</td>
<td></td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Abstract #</td>
<td>Project ID #</td>
<td>Focus Area</td>
<td>Project Title</td>
<td>Fills Critical Info Need <em>(1 High, 3 Low)</em></td>
<td>Likelihood for Success <em>(1 High, 3 Low)</em></td>
<td>Estimated Budget ($)</td>
<td>Estimated Project Timeline (Boxes in Red Indicate the Duration of the Project)</td>
<td>One Per Category</td>
<td>5 Favorites</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>-----------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>------------------------------------------</td>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>-----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>28</td>
<td>27</td>
<td>Methods</td>
<td>Broad Spectrum Screening of Drugs and EDCs in Waters by Comprehensive using innovative techniques</td>
<td>2</td>
<td>1</td>
<td>800,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>4</td>
<td>42</td>
<td>Customer Outreach &amp; Regulatory</td>
<td>Developing Practical Health Advice as Context for Contaminant Risk Communication</td>
<td>1</td>
<td>2</td>
<td>200,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>16</td>
<td>45-52</td>
<td>Treatment</td>
<td>Industry Benchmarks for Treatment Strategies (Guidance Manual for development of multiple or hybrid unit processes to remove EDC/PPCPs and to consider a watershed scale assessment (life-cycle assessment / watershed risk-benefit to remove EDC/PPCP at WTP or WWTPs))</td>
<td>1</td>
<td></td>
<td>400,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>23</td>
<td>53</td>
<td>Source Water Protection and Occurrence</td>
<td>Occurrence, Fate and Transport of EDCs and PPCPs in Distribution Systems * Should be moved to strategic initiative on distribution systems</td>
<td>2.5 *</td>
<td>2</td>
<td>350,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>11</td>
<td>30</td>
<td>Treatment</td>
<td>Evaluation of the Potential for Toxic By-Products Formation During Advanced Oxidation Process Treatment of PPCPs and EDCs in Drinking Water Sources</td>
<td>2</td>
<td></td>
<td>600,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>21</td>
<td>6-7</td>
<td>Source Water Protection and Occurrence</td>
<td>Survey of EDCs in Surface Water Supplies Used by Community Water Systems</td>
<td>2</td>
<td>1</td>
<td>1,350,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>Source Water Protection and Occurrence</td>
<td>Addressing Impacts Related to Expanded Wastewater Discharge and Reuse on Source Water Quality and Perception</td>
<td>2</td>
<td>2</td>
<td>100,000</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>Abstract #</td>
<td>Project ID #</td>
<td>Focus Area</td>
<td>Project Title</td>
<td>Fills Critical Info Need <em>(1 High, 3 Low)</em></td>
<td>Likelihood for Success <em>(1 High, 3 Low)</em></td>
<td>Estimated Budget ($)</td>
<td>Estimated Project Timeline (Boxes in Red Indicate the Duration of the Project)</td>
<td>One Per Category</td>
<td>5 Favorites</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------</td>
<td>------------------------------------------</td>
<td>---------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>------------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>44</td>
<td>Customer Outreach &amp; Regulatory</td>
<td>Strategy for Developing Alliances, to Effectively Manage the Complexities Associated With EDCs/PPCPs.</td>
<td>1</td>
<td>2</td>
<td>100,000</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>Treatment</td>
<td>Use of GAC for Control of EDCs and PPCPs in Drinking Water</td>
<td>2</td>
<td></td>
<td>400,000</td>
<td>check on start</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>Treatment</td>
<td>Removal of Emerging Organic Contaminants by Chlorine, Chlorine Dioxide, Ozone and Chloramine Disinfection Processes</td>
<td>2</td>
<td></td>
<td>400,000</td>
<td>check on start</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>40</td>
<td>Moved from Source</td>
<td>Impacts of Nanomaterials in Source Waters on the Fate and Transport of EDCs and PhACs Through Drinking Water Treatment Processes</td>
<td>3</td>
<td></td>
<td>150,000</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>41</td>
<td>Treatment</td>
<td>Removal of Trace Organic Contaminants from Water Using Point of Use Devices</td>
<td>3</td>
<td></td>
<td>200,000</td>
<td>check on start date</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>21-36</td>
<td>Source Water Protection and Occurrence</td>
<td>EDC and PPCP Sewershed Contributions from Targeted Sources and Evaluation of Cost Effectiveness of Pretreatment Compared to Wastewater Treatment Upgrades</td>
<td>2</td>
<td>1</td>
<td>1,200,000</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>4B</td>
<td>Toxicology &amp; Health Effects</td>
<td>Prioritizing Schedule to help design future research on naturally occurring and synthetic contaminants that are potential EDCs related to human health</td>
<td>1</td>
<td>2</td>
<td>200,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Top-voted Project in Each Focus Area

<table>
<thead>
<tr>
<th>Abstract #</th>
<th>Focus Area</th>
<th>Project Title</th>
<th>Votes</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Toxicology and Health Effects</td>
<td>Handbook of Screening Values for Unregulated Contaminants such as EDC, Pharmaceuticals, and PCP Ingredients</td>
<td>26</td>
</tr>
<tr>
<td>27</td>
<td>Methods</td>
<td>Method Validation by Inter-laboratory Comparison for Priority Pharmaceuticals (GWRC)</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Customer Outreach &amp; Regulatory</td>
<td>Interim Water Utility Strategy Plan for Responding to Emerging Contaminants Challenges</td>
<td>15</td>
</tr>
<tr>
<td>18</td>
<td>Source Water Protection and Occurrence</td>
<td>Characterization of Source Water Quality, Finished Water Quality, and Treatment Process Effectiveness Related to EDCs and PPCPs</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>Treatment</td>
<td>Assessment of Quantitative Structure Property Relationships (QSPR) Techniques to Predict Removal of EDC/ PPCPs in Drinking Water Treatment</td>
<td>9</td>
</tr>
</tbody>
</table>
**Literature Overview**

**Endocrine Disruptor Compounds and Pharmaceuticals and Personal Care Products**

**Introduction**

The purpose of this document is to provide a high level overview of the literature associated with endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) to inform a discussion of research needs for the Awwa Research Foundation. This document will provide background information for a Five-Year Research Needs Planning Workshop to be held by the AwwaRF on October 2-3, 2007 in Marina Del Rey, California.

A growing body of scientific research indicates that various synthetic chemicals could interfere with the normal functioning of endocrine systems of human and other species. The primary function of the endocrine system is to maintain a stable environment within the body, referred to as homeostasis. The endocrine system also controls reproduction and growth. Recently, public concern has focused on the possible disruption of normal endocrine activities due to the presence of minute quantities of some environmental chemicals. These chemicals, referred collectively as endocrine disruptors comprise a wide range of compounds including natural and synthetic hormones, herbicides, pesticides, surfactants, and plasticizers. Many of these chemicals have been linked to developmental, reproductive, neural, immune, and other problems. More recently pharmaceuticals and personal care products (PPCPs) have been discovered in various surface and ground waters. While the majority of the PPCPs may be benign at the trace concentrations that they occur in the environment, some have been linked to adverse ecological impacts, even at the low, ambient levels. With the continued advancement in analytical chemistry, the scientific community has gained a significant volume of information on these chemicals in the past few years. Disinfection byproducts (DBPs) such as halomethanes, haloacetonitriles, haloacids, halonitromethanes, and nitrosamines, have also been identified as having real and potential human health effects (some posing potential reproductive and developmental effects). However, the current review focuses on endocrine disrupting compounds that are outside the DBP group.
What are EDC/PPCPs?
The United States Environmental Protection Agency (USEPA) defined EDCs as “exogenous agents that interfere with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis, reproduction, development, and/or behavior” (EPA, 1997). However, definitions and opinions on what defines an EDC vary greatly. It is generally accepted that the three major endocrine disruption pathways are estrogenic (compounds that mimic or block natural estrogen), androgenic (compounds that mimic or block natural testosterone), and thyroidal (compounds with direct or indirect impacts to the thyroid) (Snyder et al., 2003b). The majority of research thus far has focused only on estrogenic compounds; however, disruption of androgen and thyroid function may be of equal or greater importance biologically.

Pharmaceutically Active Compounds (PhACs) are defined as “chemicals used for diagnosis, treatment (cure/mitigation), alteration or prevention of disease, health condition, or structure/function of the human body” (Daughton and Ternes, 1999). Pharmaceuticals also include products used in veterinary health care. Personal care products that may have an adverse ecological effect include fragrances, preservatives, disinfectants/antiseptics, and sunscreen agents.

Occurrence of EDCs in Drinking Water
EDCs have been found in trace amounts (parts per trillion (ppt) to parts per billion (ppb) levels) in surface water supplies, including lakes and streams (Weyer and Riley, 2001). Considerable amount of research is already completed to underscore the occurrence of possible EDCs. PhACs are used widely by the general public and has the potential of widespread occurrence as unmetabolized portion of these chemicals are released to the environment (Sedlak et al, 2005). Some of these compounds are lipophilic (i.e., soluble in fat) and persist in the recipient’s body and in the environment. Therefore they have many of the properties necessary to bioaccumulate and possibly produce effects in ecological systems (Halling-Sorensen et al., 1998). While the concentration of
individual compounds is low, the presence of numerous compounds sharing a specific mode of action could lead to measurable effects through additive exposures (Daughton and Ternes, 1999). Exposures to these compounds may be of a chronic nature because these substances are constantly introduced into the environment via human wastewater treatment, livestock production, etc (Ternes and Hirsch, 2000, Ternes et al., 1995, Ternes et al., 1999a, Ternes et al., 1999b).

**Surface Water**

In surface waters (specifically in rivers, lakes, and coastal waters) throughout Europe and the U.S., roughly 100 pharmaceuticals have been observed most frequently (Snyder et al., 2003b). Table 1 shows several of these most frequently detected compounds along with their usage and concentration in U.S. streams. As can be seen from the Table, the most commonly detected compounds include biogenic and synthetic hormones, sterols, and household and industrial wastewater products.

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Use</th>
<th>Frequency of Detection (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cholesterol</td>
<td>Plant/ Animal Steroid</td>
<td>~ 80%</td>
</tr>
<tr>
<td>N-N-diethyltoluamide</td>
<td>Mosquito Repellent</td>
<td>~ 75%</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Stimulant</td>
<td>~ 75%</td>
</tr>
<tr>
<td>Tris(2-chloroethyl)phosphate</td>
<td>Fire Retardant</td>
<td>~ 75%</td>
</tr>
<tr>
<td>Triclosan</td>
<td>Antibiotic</td>
<td>~ 60%</td>
</tr>
<tr>
<td>4-Nonylphenol</td>
<td>Surfactant</td>
<td>~ 60%</td>
</tr>
<tr>
<td>4-Nonylphenol monoethoxylate</td>
<td>Surfactant</td>
<td>~ 60%</td>
</tr>
<tr>
<td>Ethanol, 2-butoxy-phosphate</td>
<td>Plasticizer</td>
<td>~ 45%</td>
</tr>
<tr>
<td>4-Octylphenol monoethoxylate</td>
<td>Surfactant</td>
<td>~ 45%</td>
</tr>
<tr>
<td>Bisphenol A</td>
<td>Plasticizer</td>
<td>~ 45%</td>
</tr>
<tr>
<td>Coprostanol</td>
<td>Estrogen</td>
<td>~ 80%</td>
</tr>
<tr>
<td>Cotinine</td>
<td>Nicotine Metabolite</td>
<td>~ 35%</td>
</tr>
<tr>
<td>4-Nonylphenol diethoxylate</td>
<td>Surfactant</td>
<td>~ 35%</td>
</tr>
<tr>
<td>5-Methyl-1H-benzotriazole</td>
<td>Antioxidant</td>
<td>~ 30%</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>PAH</td>
<td>~ 30%</td>
</tr>
<tr>
<td>1,7,-Dimethylxanthine</td>
<td>Caffeine Metabolite</td>
<td>~ 30%</td>
</tr>
<tr>
<td>Pyrene</td>
<td>PAH</td>
<td>~ 25%</td>
</tr>
<tr>
<td>Trimethoprim</td>
<td>Antibiotic</td>
<td>~ 25%</td>
</tr>
<tr>
<td>1,4-Dichlorobenzene</td>
<td>Deodorizer</td>
<td>~ 25%</td>
</tr>
<tr>
<td>Acetaminophen</td>
<td>Analgesic</td>
<td>~ 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>Solvent</td>
<td>~ 20%</td>
</tr>
<tr>
<td>4-Octylphenol diethoxylate</td>
<td>Surfactant</td>
<td>~ 20%</td>
</tr>
<tr>
<td>Erythromycin-H₂O</td>
<td>Antibiotic</td>
<td>~ 20%</td>
</tr>
<tr>
<td>Estriol</td>
<td>Estrogen</td>
<td>~ 20%</td>
</tr>
<tr>
<td>Lincomycin</td>
<td>Antibiotic</td>
<td>~ 15%</td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>Antibiotic</td>
<td>~ 15%</td>
</tr>
<tr>
<td>Phthalic anhydride</td>
<td>Plasticizer</td>
<td>~ 15%</td>
</tr>
<tr>
<td>Carbaryl</td>
<td>Insecticide</td>
<td>~ 15%</td>
</tr>
</tbody>
</table>

Various studies have shown EDCs to be present in surface waters. A United States Geological Survey (USGS) study (Barber et al., 1995) on the Mississippi River found widespread occurrence of caffeine, the highest concentrations generally detected near populated areas. Hirsch et al. (1999) listed the results of surveillance studies for 18 antibiotics in sewage treatment plants and surface water. Kolpin et al. (1999) sampled 31 surface water sites for 15 antibiotics and found detection in over one-half the sites. Buxton (2000) looked at 15 biogenic and synthetic hormones and sterols, as well as 35 household and industrial wastewater products in 30 U.S. streams. In that study, the most commonly detected compounds (> 40% of samples) included ethanol-2-butoxyphosphate, triclosan, tri(2-chloroethyl)phosphate, NP, NPE, and bisphenol A, while the most commonly detected hormones included cholesterol, 3b-coprostanol, and 17b-estradiol. Rudel et al. (1998) showed that drinking water supplies on Cape Cod were impacted by septic systems leakage of alkylphenol polyethoxylates. A U.S. Centers for Disease Control and Prevention Study (Campagnolo and Rubin, 1998) found antibiotic residues in hog manure lagoons in a monitoring well surrounding a lagoon.

Pharmaceuticals have also been widely reported in the European surface water sources. Buser et al. (1998) detected clofibric acid and mecoprop in Swiss lakes and in the North Sea in the low parts per trillion (ppt) range, and diclofenac has been detected in Swiss rivers and lakes (Stan et al., 1994). It has been suggested that clofibric acid in the environment is a mobile and persistent contaminant. Ibuprofen is a commonly detected compound in European surface waters (Buser et al., 1999). In a German study, Kumerrer et al. (1998) looked at adsorbable organically bound halogens (AOX), which are persistent in the environment, can accumulate in the food chain, and can be toxic to humans. The Kumerer study found that 6-11% of AOX concentrations in the effluents of
6 hospitals were attributable to PhAcs. Heberer and Stan (1997) reported finding clofibric acid in drinking water in Berlin.

**Groundwater**

Groundwater studies of PhACs have shown few detections. Seiler et al. (1999) have used detections of caffeine as an indicator of other contamination in groundwater. Holm et al. (1995) reported the occurrence of multiple pharmaceuticals in a leachate plume from a landfill where a pharmaceutical manufacturer buried waste. The heaviest concentrations of the compounds were detected closest to the landfill, suggesting that soil microbials may help in degradation. Hirsch et al. (1999) report few detections from groundwater samples beneath an area where animal manure was applied as fertilizer. Antibiotics were detected in groundwater in Germany – it is believed that they leached from a nearby sewage facility through bank filtration (Heberer et al., 1997).

**Sources of EDCs and PPCPs**

While some estrogenic compounds occur naturally, most of the detected estrogenic compounds are introduced from man-made sources (e.g., waste discharges from municipalities and industries as well as water from urban and agricultural areas). The relative contribution of urban versus rural sources of contaminants, particularly with respect to herbicides and other pesticides is debatable. In a German study, Nitschke and Schussler (1998) showed that urban wastewater plant effluent contributes a large proportion of the herbicide pollution of proximate surface water supplies.

PPCPs can be introduced into the environment via similar discharges mentioned above. Antibiotics have the potential for contamination of water resources because a substantial portion of the drugs administered leave the body as a mixture of parent compounds and metabolites via urine or feces (Halling-Sørensen et al., 1998).

**Environmental Fate of EDCs/ PPCPs**

The risk of EDCs and PPCPs to humans and the environment is strongly influenced by their fate and behavior in the environment (Ying et al., 2004). The fate of EDC/ PPCPs
in the environment is expected to vary greatly with the compound in question. For example 17β-estradiol is generally found at ng/L levels in the environment, it has low persistence in water and soil (less than a week) and has moderate affinity for sorption on organic carbon (K_{oc}) and mobility in the environment (Ying et al., 2003). In contrast, endosulfan is usually detected in μg/L level, shows much longer persistence in water and soil (an average half-life of 50 days), and has much higher K_{oc} and low mobility with water. The high value of Koc, representing greater sorption affinity for organic carbon, indicates greater potential of the compound to be associated with the solid phase rather than the liquid phase. NP has been reported to rapidly dissipate in soils with an estimated half-life ranging from 4.5 days to 16.7 days (Topp and Starratt, 2000).

EDCs may possess differential lipophilicity or hydrophilicity resulting in different retention rates and bioavailability in nature (Huang et al., 2003). For example, though chemicals such as DDT and nonylphenols are less potent than endogenous hormones and synthetic hormones (released by organisms), their lipophilicity allow them to exist for a prolonged period of time in ecosystems and be passed on to higher trophic levels. Their long-term, chronic effects and biomagnification may have more important implications than those of short-life chemicals. Another aspect is that EDCs are subject to differential biological metabolism which yields either bioactivation or bioinactivation. Either way will impose quite different ecological consequences.

The environmental fate and behavior of EDCs and PPCPs may also vary greatly with temperature and the matrix in which they are present (Vikesland et al., 2006). As a result, their breakdown rates and persistence are different in environmental compartments such as water, soil, and air. A recent AwwaRF project (AwwaRF, 2006) conducted in United States and United Kingdom studied the impacts of the degradates of pesticides on drinking water quality. The study developed a risk-based prioritization approach that considered the usage of parent substances, the formation of degradates, and their potential to be transported to surface waters, and grounds, as well as potential impacts on human health. The rate of removal of EDCs during treatment can depend on several factors.
including the chemical nature of the compound, the treatment technology, and the climatic conditions.

**Toxicity and Health Effects**

*Toxicological pathway*

Researchers have learned much about the mechanisms through which endocrine disruptors influence the endocrine system and alter hormonal functions. Endocrine disruptors can:

- Mimic or partly mimic naturally occurring hormones in the body like estrogens (the female sex hormone), androgens (the male sex hormone), and thyroid hormones, potentially producing overstimulation.
- Bind to a receptor within a cell and block the endogenous hormone from binding. The normal signal then fails to occur and the body fails to respond properly. Examples of chemicals that block or antagonize hormones are anti-estrogens or anti-androgens.
- Interfere or block the way natural hormones or their receptors are made or controlled, for example by blocking their metabolism in the liver.

*Ecological Health Effects*

Significant literature is available on impacts of EDCs on fish and wildlife. Wildlife effects are mainly related to developmental abnormalities, either from exposure during prenatal or early postnatal life, or from direct exposure of offspring after birth or hatching (Colborn et al., 1993). Transgenerational exposure can result from exposure to the mother at any time prior to producing the offspring due to the persistence and accumulation of EDCs in body fat. At least 70 separate studies of the endocrine effects of specific chemicals on birds, fish, mammals, and molluscs were published between 1970 and 1995 (Krimsky, 2000, Kiwa Water Research, 2003). EPA has found a common mechanism of toxicity for several triazines that result in disruption of the hypothalamic-pituitary-gonadal (HPG) axis (USEPA, 2002). Adverse health impacts in wildlife species exposed to EDCs in ambient surface water supplies are well documented. Studies have reported developmental problems with alligators in Florida lakes (Guillette, 1995),
developmental abnormalities in male fish living in the effluents of wastewater treatment plants (Jobling and Sumpter, 1993), and developmental problems in laboratory animals exposed to estrogenic substances (Chang et al., 1999).

Naturally occurring estrogens known as phytoestrogens have also been implicated in endocrine disruption (Barrett, 1996). Sheep grazing on certain strains of clover in New Zealand exhibited severe reproductive impairment due to phytoestrogens (Adams, 1998). The inability of captive Cheetahs at the Cincinnati Zoo was linked to a diet high in phytoestrogens (Setchell et al., 1987).

Little is known with respect to PhAC toxicity in wildlife. Unknowns include whether PhACs and their metabolites can elicit effects on biota at the low concentrations (ppb, ppt) found in the environment, and what the actual quantity of each of the contaminants is that is ingested/ excreted (Daughton and Ternes, 1999). In the laboratory, the toxicity of salicylic acid, paracetamol, clofibrin acid and methotrexate on algae, Daphnia, fish embryos and bacteria were measured by Henschel et al. (1997). The EC50 values calculated were 37 mg/L for salicylic acid in fish embryos, 50 mg/L for paracetamol in Daphnia, 86 mg/L for clofibrin acid in fish embryos, and 45 mg/L for methotrexate in ciliates. In a Danish risk assessment for 25 commonly used PhACs, Stuer-Lauridsen et al. (2000) calculated predicted environmental concentrations (PECs) for the aquatic environment, and found PECs for all compounds were >1 ppt. A predicted no-effect concentration (PNEC) based on aquatic ecotoxicity was then calculated for 6 of the PhACs. The PEC/PNEC ratio was >1 for ibuprofen, acetylsalicylic acid, and paracetamol, indicating potential problems for aquatic species exposed to these compounds at very low concentrations.

**Human Health Effects**

The unexpected impacts of trace concentrations of EDCs on wildlife raised concerns about the potential effects of these chemicals on humans. The connection between endocrine disruption in wildlife and potentially adverse health effects in humans was theorized by Theo Colburn, of the World Wildlife Fund, in her book “Our Stolen Future”
(Colborn et al., 1997). However, if EDCs cause adverse human health effects, chances are much higher that these effects are caused by phytoestrogens and other estrogenic compounds present in food sources. Concentrations of estrogenic compounds in water are extremely minute compared to the concentrations that are likely to be present in food sources, thus lowering the probability of endocrine disruption caused by waterborne estrogens. Some of the adverse human health effects that are suspected to be caused by environmental exposure to EDCs are presented here.

Some researchers have attributed decreases in human sperm quality and quantity over the past five decades to endocrine disrupting compounds in the environment (Carlsen et al., 1995). However, this topic is still quite controversial, and other studies have produced data refuting these arguments (Safe and Gaido, 1998). Some researchers suggest that geographic variation and other cultural variables may be more important factors than EDCs in controlling human sperm counts (Fisch and Goluboff, 1996). Studies have also looked at the possible role of exogenous estrogenic substances in the development of breast cancer. Moysich et al. (1999) found that among post-menopausal women with serum PCB level above the median of the study control group, there was an increased risk of breast cancer associated with the presence of allele involved in CYP1A1 enzyme induction. PCBs are known to induce CYP1A1, which is involved in the metabolism of steroid hormones.

Neurological and reproductive disorders have also been studied as possible adverse endpoints of exposure to EDCs. An outbreak of Yusho disease was linked to exposure to PCBs in Japan (Rogan et al., 1988). A mother’s consumption of Great Lakes fish with high PCB tissue levels has been implicated with impaired cognitive development in their children (Jacobson et al., 1996), and prenatal exposure to PCBs was also associated with psychomotor developmental deficits in children in a North Carolina study (Gladen et al., 1988). A theory has been set forth that fetuses may be more sensitive than newborns and children to xenobiotics due to a lack of detoxification mechanisms in the fetus and other factors (Jacobsen et al., 1990). In addition it has been shown that EDCs can impair
thyroid hormone mediated events during development, which can result in brain function abnormalities in adults (Cooper and Kavlock, 1997).

The literature does not cite any specific study investigating human health issues associated with PhAC exposures. There has been concern that bacterial resistance to antibiotics may result due to long term contact with low levels of antibiotics in the environment. Commonly used PhACs are generally given to humans in much higher doses than what is being found in the environment. Effects from exposure to small concentrations of PhACs that may be in the environment or in drinking water and the long term exposure to these are still open to debate. However, some studies have examined PhACs that are not widely used. Richardson and Bowron (1985) found a negligible human risk connected to exposure to 17a-ethinylestradiol, cyclophosphamide, and phenoxyethylpenicillin, using the EUSES software.

Additive Effects of EDCs
The effects of multi-component mixtures of EDCs have been assessed by several researchers (Arnold et al., 1996, Daston et al., 2003). These studies have demonstrated that the combination effects of EDCs can be estimated by ‘dose addition’. It was observed that because similar categories of EDCs interact with well-defined molecular targets, one chemical can be replaced totally or in-part by an equal fraction of an equi-effective concentration of another, without diminishing the overall combined effect. A recent review (Kortenkamp, 2007) concluded that joint effects can occur even when all mixture components are present at levels below doses that cause observable effects. The review summarizes several studies where individual compounds present in a ‘low dose’ did not cause any detrimental health effect, but the mixture of several compounds (each at a low dose) had a significant impact. The Kortenkamp study concluded by suggesting that grouping of EDCs according to their ability to induce similar effects (as opposed to similar mechanisms) may be the most appropriate method for mixture exposure assessment.

Analysis Methods
Because EDCs and PPCPs represent structurally diverse classes of compounds, a plethora of analytical methods have been, or could be, applied for the identification and quantification of these chemicals in water. The measurement of EDCs in water most commonly consists of an extraction of the chemicals from water, concentration of the resulting extract, chromatographic separation, and detection.

EDCs have been known to induce biological responses in aquatic organisms at sub-μg/L concentrations (Saal et al., 2005), and so analytical techniques for these compounds in water have been designed to achieve detection limits in ng/L. As the majority of analytical instruments are unable to directly detect compounds at these levels, an extraction step is required to concentrate the target compounds to a detectable level. Conventional techniques such as liquid-liquid, Soxhlet, and steam distillation have been used to extract EDCs from water, however solid-phase extraction (SPE) is the most common technique employed for sample enrichment. Variations of SPE include solid-phase microextraction (SPME) and various on-line and automated SPE techniques.

Gas Chromatography (GC) and Liquid Chromatography (LC) are the most commonly used analytical instruments for EDC detection and measurement (Snyder et al., 2007, Ternes et al., 1998). A mass spectrometer (MS) is the most sensitive and selective detector used with these instruments. Different types of mass spectrometers used for EDC analysis include ion trap, magnetic/electric sector, single and triple quadrupole, time-of-flight (TOF), Fourier-transform, and hybrid mass spectrometers. Some mass analyzers (i.e. ion trap, triple quadrupole) can perform tandem mass spectrometry (MS/MS) where the analyte is ionized and then fragmented to yield product ions. Vanderford et al. (2003) developed a method for the analysis of 27 EDCs and PPCPs using SPE and LC/MS/MS using electrospray ionization in both positive and negative modes and atmospheric pressure chemical ionization in positive mode. Instrument detection limits for most compounds with this method were below 1 ng/L and recoveries were greater than 80%.

| Table 2: Methods for Frequently Analyzed EDCs and PPCPs (Snyder et al., 2007) |
|-----------------|-------------|----------------|-------------|
| Target          | Extraction  | Chromatography | Detection   |

11
<table>
<thead>
<tr>
<th>Compound</th>
<th>Derivatization Method</th>
<th>Detector Method</th>
<th>Limit Range (ng/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Androstenedione</td>
<td>SPE</td>
<td>Derivatize GC/MS, GC/MS/MS</td>
<td>0.1 – 1</td>
</tr>
<tr>
<td>Ethynyl estradiol</td>
<td>SPE, SPME</td>
<td>Derivatize GC/MS or GC/MS/MS,</td>
<td>0.2 – 400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC/MS, LC/MS/MS, HPLC/UV or</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>electrochemical detector</td>
<td></td>
</tr>
<tr>
<td>Estradiol</td>
<td>SPE, SPME</td>
<td>Derivatize GC/MS or GC/MS/MS,</td>
<td>0.2 - 400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC/MS, LC/MS/MS, HPLC/UV or</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>electrochemical detector</td>
<td></td>
</tr>
<tr>
<td>Estriol</td>
<td>SPE</td>
<td>Derivatize GC/MS or GC/MS/MS,</td>
<td>0.3 – 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC/MS, LC/MS/MS</td>
<td></td>
</tr>
<tr>
<td>Estrone</td>
<td>SPE, SPME</td>
<td>Derivatize GC/MS or GC/MS/MS,</td>
<td>0.1 – 700</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC/MS, LC/MS/MS, HPLC/UV or</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>electrochemical detector</td>
<td></td>
</tr>
<tr>
<td>Progesterone</td>
<td>SPE</td>
<td>Derivatize GC/MS, HPLC/DAD</td>
<td>1 – 20</td>
</tr>
<tr>
<td>Testosterone</td>
<td>SPE</td>
<td>Derivatize GC/MS, GC/MS/MS</td>
<td>0.2 – 1</td>
</tr>
<tr>
<td>Antimicrobials</td>
<td></td>
<td>LC/MS, LC/MS/MS</td>
<td>0.03 – 50</td>
</tr>
<tr>
<td>Erythromycin</td>
<td>SPE</td>
<td>LC/MS, LC/MS/MS</td>
<td>6 – 104</td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>SPE</td>
<td>LC/MS, LC/MS/MS</td>
<td>6 – 104</td>
</tr>
<tr>
<td>Triclosan</td>
<td>SPE</td>
<td>GC/MS</td>
<td>0.16</td>
</tr>
<tr>
<td>Trimethoprim</td>
<td>SPE</td>
<td>LC/MS, LC/MS/MS</td>
<td>1 – 27</td>
</tr>
<tr>
<td>Analgesics</td>
<td></td>
<td>LC/MS, LC/MS/MS</td>
<td>8.6</td>
</tr>
<tr>
<td>Acetaminophen (Tylenol)</td>
<td>SPE</td>
<td>LC/MS, LC/MS/MS</td>
<td></td>
</tr>
<tr>
<td>Diclofenac</td>
<td>SPE, SPME, LPME</td>
<td>Derivatize GC/MS, LC/MS/MS,</td>
<td>&lt;1 – 45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CE/MS, HPLC/ fluorescence detector</td>
<td></td>
</tr>
<tr>
<td>Ibuprofen (Advil)</td>
<td>SPE, LLE, SPEM, LPME</td>
<td>Derivatize GC/MS, CE/MS, LC/MS,</td>
<td>&lt;1 – 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC/MS/MS, HPLC/ fluorescence detector</td>
<td></td>
</tr>
<tr>
<td>Naproxen</td>
<td>SPE, SPME, LPME</td>
<td>Derivatize GC/MS, CE/MS, LC/MS,</td>
<td>&lt;1 – 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HPLC fluorescence detector</td>
<td></td>
</tr>
<tr>
<td>Psychoactive Compounds</td>
<td></td>
<td>GC/MS, LC/MS/MS</td>
<td>0.26 – 19</td>
</tr>
<tr>
<td>Caffeine</td>
<td>SPE</td>
<td>Derivatize GC/MS</td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>SPE, LPME, LLE</td>
<td>Derivatize GC/MS, LC/MS/MS,</td>
<td>1 – 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HPLC fluorescence detector</td>
<td></td>
</tr>
<tr>
<td>Diazepam (Valium)</td>
<td>SPE, LLE</td>
<td>GC/MS, LC/MS/MS</td>
<td>0.02 – 100</td>
</tr>
<tr>
<td>Dilantin</td>
<td>SPE</td>
<td>LC/MS/MS</td>
<td>1</td>
</tr>
<tr>
<td>Fluoxetine (Prozac)</td>
<td>SPE, SPME</td>
<td>Derivatize GC/MS, LC/MS/MS</td>
<td>1 – 18</td>
</tr>
<tr>
<td>Meprobamate</td>
<td>SPE</td>
<td>LC/MS/MS</td>
<td>1</td>
</tr>
<tr>
<td>Pesticides</td>
<td></td>
<td>GC/MS, LC/MS, LC/MS/MS</td>
<td>0.2 – 20</td>
</tr>
<tr>
<td>Atrazine</td>
<td>SPE</td>
<td>GC/MS, LC/MS, LC/MS/MS</td>
<td>3 – 8</td>
</tr>
<tr>
<td>DDT</td>
<td>SPE, SPME</td>
<td>GC/ECD, GC/MS</td>
<td></td>
</tr>
<tr>
<td>DEET</td>
<td>SPE</td>
<td>GC/MS</td>
<td>0.026 – 0.082</td>
</tr>
</tbody>
</table>
Bioanalytical techniques are important tools for monitoring certain EDCs and PPCPs. These techniques employ a biological end point that is related to a type of toxicity or a class of compounds. The simplest methods are receptor binding assays and cellular bioassays that have rapid response times, high sensitivity, and relatively low cost (Snyder et al., 2001). Both in vivo and in vitro bioassays are used to detect various classes of EDCs (Hemming et al., 2004). The use of DNA microarrays as a bioanalytical tool for analysis of pharmaceutical contamination in reuse waters was investigated in a recent research (Kullman et al., 2007). When fully developed, this bioanalytical approach is expected to provide an efficient and robust method for screening pharmaceutical contaminants in reuse and other water matrices. A combination of instrumental and bioanalytical techniques is generally used to detect and quantify EDCs.

### Drinking Water Treatment Processes for EDCs

A number of drinking water treatment processes may be somewhat effective at removing EDCs, based on molecular weight and molecule size (Carlson, 2000). A literature review of EDC/PPCP treatment was published by Snyder et al. (2003a), which reported that certain treatment processes provide the greatest removal of these compounds, while other

---

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Extraction/Enrichment</th>
<th>Detection</th>
<th>Detection Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindane (γ-BHC)</td>
<td>SPE, SPME</td>
<td>GC/ECD, GC/MS</td>
<td>1.3 – 20</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>SPE, SPME</td>
<td>GC/MS, GC/MS/MS</td>
<td>0.1 – 5</td>
</tr>
<tr>
<td><strong>Fragrances</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galaxolide</td>
<td>SPE, SPME, closed loop stripping analysis</td>
<td>GC/MS</td>
<td>1 – 6</td>
</tr>
<tr>
<td>Musk Ketone</td>
<td>Closed loop stripping analysis</td>
<td>GC/MS</td>
<td>10</td>
</tr>
<tr>
<td><strong>Polycyclic Aromatic Hydrocarbons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzo(a)pyrene</td>
<td>SPE, SPME</td>
<td>GC/MS</td>
<td>2 - 120</td>
</tr>
<tr>
<td>Fluorene</td>
<td>LLE, SPME</td>
<td>GC/FID, GC/MS</td>
<td>10</td>
</tr>
<tr>
<td><strong>Heart Medications</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gemfibrozil</td>
<td>SPE, LLE</td>
<td>Derivatize GC/MS, LC/MS, LC/MS/MS</td>
<td>1 – 90</td>
</tr>
<tr>
<td>Pentoxifylline</td>
<td>SPE</td>
<td>LC/MS/MS</td>
<td>1</td>
</tr>
<tr>
<td><strong>Flame Retardant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCEP</td>
<td>SPE, LLE</td>
<td>GC/MS</td>
<td>1, 40</td>
</tr>
<tr>
<td><strong>Sunscreen</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxybenzone</td>
<td>SPE</td>
<td>GC/MS</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>X-ray Contrast Media</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iopromide</td>
<td>SPE</td>
<td>LC/MS/MS</td>
<td>1 – 10</td>
</tr>
</tbody>
</table>
processes are not as effective. The feasibility of using a certain technique will depend on the size of the system, the technical complexity (which determine the needed skills for the system operators), and the cost effectiveness (Ternes, 2004).

While evaluating EDC removal, the difference between physical and chemical removal of EDCs should be taken into consideration. Processes such as coagulation, activated carbon, and membranes physically remove or adsorb the compounds, thus eliminating them. Chemical removal generates oxidation byproducts, which create concerns as to whether the byproducts pose a human or environmental health risk. For instance, deethylatrazine is a degradation product of atrazine, which has been found to exhibit acute lethal effect to aquatic organisms due to synergistic interactions with organophosphate insecticides (Trimble and Lydy, 2006).

An evaluation of the effectiveness of different drinking water treatment unit operations is summarized in Table 3. A brief review of the performance of each of the applicable treatment processes is summarized below.

| Table 3: Performance of Drinking Water Treatment Processes (adapted from KWR, 2004) |
|-----------------------------------------------|----------------------|
| Unit Operation                                | % Removal            |
| Activated Carbon                              | 70 - >90             |
| Ozonation/ Advanced Oxidation                 | 20 - >90             |
| UV                                            | 40 – 90              |
| Cl₂/ClO₂                                      | <20 – 40             |
| Softening/ Metal Oxide                        | <20 - 20             |
| Coagulation/ Flocculation                     | <20 – 20             |
| Nanofiltration                                | 70 - >90             |
| RO                                            | >90                  |

Coagulation/ Flocculation
Coagulation/ flocculation has been shown to be ineffective in removing most PPCPs and EDCs, typically removing less than 25% (Westerhoff, 2003). Carbamazepine and primidone, known to be persistent in the environment, were not affected by coagulation, even at influent concentrations as high as 1000 ng/L (Ternes et al., 2002). Less than 20% of diclofenac, ibuprofen, naproxen, and ketoprofen was removed during coagulation by
ferric at various pH conditions (Vieno, Tuhkanen, and Kronberg, 2005). While majority of the research shows minimal removals through coagulation, much higher removals of steroid hormones during coagulation using a special aluminum coagulant (PAX-18) were recently reported (Bodzek and Dudziak, 2006).

Adsorption on Activated Carbon

GAC and PAC are efficient in removing hydrophobic organic contaminants despite the competitive effects from Natural Organic Matter (NOM), which tend to decrease the adsorption of organic compounds. The USEPA identifies packed-bed granular activated carbon as a “Best Available Technology” (BAT) for treating numerous regulated organic pollutants (Westerhoff, 2005). GAC and PAC demonstrated greater than 75% removal of many EDCs and PPCPs (Westerhoff, 2003), but a number of factors affect removal efficiency including hydrophobicity, charge, and molecular size. Removal of neutral species by GAC/ PAC was shown to be related to the octanol-water partition coefficient (K_{ow}) in a number of studies. Yoon et al. (2003) illustrated the relationship between log K_{ow} and extent of activated carbon removal for compounds such as bisphenol A, estradiol, and ethynyl estradiol. Some charged species showed less removal than neutral species (Westerhoff et al., 2005), whereas some other species exhibited moderate removal regardless of charge (Speth and Miltner, 1998). The removal of charged species can be pH dependent. Herbicide diquat dibromide is a divalent cation and its removal by GAC is dramatically impacted by aqueous pH (Speth and Miltner, 1998). Very large molecules tend to have low removal by GAC/ PAC due to steric hindrance. In addition to different removal mechanisms, adsorption kinetics and adsorbate concentration can affect the efficiency of an activated carbon process. Using GAC, it was determined that higher initial contaminant concentrations resulted in higher percent removal for estradiol (Fuerhacker et al., 2001).

Ozone and Advanced Oxidation

Removal of EDCs and PPCPs with ozone is dependant on the chemical structures of these compounds and ozone dose. Removal of several compounds such as diclofenac, carbamazepine, bezafibrate, and estrogens with ozone has been demonstrated (Snyder et
The rate at which ozone reacts with a particular contaminant is moiety specific and pH dependent. Antibacterial substance, azithromycin, reacted rapidly with a second order reaction rate constant in the order of $10^6 \text{ M}^{-1}\text{s}^{-1}$ due to the high reactivity of neutral tertiary amine moiety. However, at low pH the protonation of amine moiety decreased the reaction rate by several orders of magnitude (Dodd et al., 2006).

Some EDC and PPCP compounds were not well removed by ozone. Two separate research studies have shown less than 40% removal of clofibrac acid by ozone under several testing conditions. Iodinated X-ray contrast media (diatrizoate, iopamidol, iopromide, and iomeprol) are also resistant to ozone oxidation, with the ionic species most resistant (Ternes et al., 2003). At a high ozone dose of 15 mg/L and a contact time of 18 min, which is much stronger than what would be normally applied at water treatment facilities, less than 14% of diatrizoate was oxidized. Advanced oxidation processes with the addition of hydrogen peroxide to promote hydroxyl radical reactions help to improve the elimination of many recalcitrant compounds during ozonation (Zweiner and Frimmel, 2000).

**Chlorine and Chlorine Dioxide**

Free chlorine can efficiently remove a significant number of EDCs and PPCPs via oxidation, substitution, and addition reactions, even though it is a weaker oxidant than ozone. Electron rich sulfamethazine and naproxen are oxidized by chlorine, while substituted aromatics with carboxylic groups like ibuprofen and ketoprofen show very weak reactivity with free chlorine (Boyd et al., 2005).

The reactivity of chlorine dioxide lies between that of free chlorine and ozone. Chlorine dioxide efficiently oxidized some emerging contaminants such as sulfonamide antibiotics and estrogens (Huber et al., 2005).

**UV**

UV at a typical disinfection dose (i.e. 40 mJ/cm²), is not expected to oxidize organic compounds. No significant removal by UV disinfection was observed for seven
representative antibiotics (Adams et al., 2002). However, UV irradiation at increased energies (>400 mJ/cm$^2$), ninety percent oxidation was achieved of estrogens at environmentally relevant levels (Linden and Kullman, 2007). At a UV fluence of 3000 mJ/cm$^2$, the seven antibiotics in the Adams study were removed by 50 – 80%. Two steroid hormones and the plasticizer bisphenol A also showed some removal by direct UV photolysis with the medium pressured lamp performing better than the low pressure lamp due to its higher energy output (Rosenfeld and Linden, 2004). Similar to ozonation, high energy UV irradiation can be combined with hydrogen peroxide for advanced oxidation. An UV advanced oxidation process (AOP) has been shown more efficient than UV alone to degrade bisphenol A, ethynyl estradiol, estradiol, and carbamazepine (Vogna et al., 2004).

Membranes
Membranes are very advantageous for micro-pollutant removal as high rejections can be obtained without the formation of byproducts. Processes such as nanofiltration (NF) and reverse osmosis (RO) are very effective at EDC and PPCP removal (Snyder et al., 2007). The rejections of contaminants vary depending on target pollutants, membrane type, feed water, and operating conditions. In a comparison between polyamide NF and RO, both membranes showed high removal (> 90%) for a group of negatively charged pharmaceuticals (Snyder et al., 2007). For neutral species, despite the decrease in rejections for both membranes, RO performance was significantly better than NF (Xu et al., 2005).

Size/ steric exclusion, electrostatic repulsion, adsorption, and diffusion mechanisms have been identified as the key factors for organic contaminant transport through membranes (Nghiem et al., 2004). Such interactions between the organic contaminant and the membrane material are determined by the coupled influence of the physicochemical characteristics of the contaminant, the membrane properties, and the solution chemistry.

Regulatory Status
Regulatory Activities in the United States
In the U.S., the first legislations related to EDCs were the amendments to both the Federal Food, Drug, and Cosmetic Act (FFDCA) and the Safe Drinking Water Act (SDWA) in August, 1996. The Food Quality Protection Act (FQPA) section of the FFDCA made substantial programmatic changes to how pesticides and other toxic substances were regulated by the EPA (Roberson, 2003). The EPA was mandated to develop a screening program to determine whether certain substances were human endocrine disruptors. Based on the results of the screening program, a second round of more detailed testing of some substances would be required. Based on the results of the additional testing, the EPA could regulate endocrine disruptors through its pesticide registration program or through the Toxic Substances Control Act.

The SDWA amendment of 1996 went beyond the potential pesticide residues in food and occupational exposure and focused on drinking water exposure. The SDWA mandated the EPA to test “any other substance that may be found in sources of drinking water if the Administrator determines that a substantial population may be exposed to such substance.” In response to the FQPA and SDWA, the EPA solicited stakeholder input and established the Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) to provide detailed advice on how to design a screening and testing program. EDSTAC issued a final report in 1998 outlining a conceptual framework consisting of an initial sorting, prioritization, Tier 1 and Tier 2 testing, and a hazard assessment of an estimated 87,000 chemicals. In addition to discrete chemicals, EDSTAC recommended the evaluation of mixtures of chemicals in breast milk, baby formulas, hazardous waste sites, pesticides and fertilizers, drinking water DBPs, and gasoline (Snyder et al., 2003a). The first draft list of 73 pesticide active ingredients and pesticide inerts to be considered for screening under the Endocrine Disruptor Screening Program (EDSP) was recently published by EPA (USEPA, 2007).

In 2001, EPA formed the Endocrine Disruptor Methods Validation Subcommittee (EDMVS) to evaluate the test battery suggested by EDSTAC. The EDMVS is tasked with method validation by determining if a particular method is transferable to other laboratories, can be validated with representative chemicals, has sufficient sensitivity to
EAT end points, and has appropriate standard operating procedures. The outcome of this screening battery is critical to the water industry, as it is designed to definitively identify EDCs. However, the current legislation regulates only the industries producing or using raw chemicals, and not the water industry. As a result, these actions may have little immediate effect on water and wastewater treatment regulations.

There are currently no federal regulations for pharmaceuticals in drinking or natural waters. Daughton and Ternes (1999) present an excellent overview of regulatory activities and priorities surrounding PhACs in the environment. The Food and Drug Administration (FDA) requires ecological testing and evaluation of a pharmaceutical only if the environmental concentration in water or soil is expected to exceed 1 μg/L or 100 μg/kg, respectively (FDA, 1998). In light of the recent data on the occurrences of PPCPs in the aquatic environment, these policies may need to be reconsidered. The State of California has been considering the potential impacts of EDCs and PPCPs, especially when municipal wastewater effluent is used for indirect potable reuse. A modification to California’s draft regulations for indirect potable reuse states, “Each year, the Planned Groundwater Recharge Reuse Project (PGRRP) shall monitor recycled water for endocrine disrupting chemicals and pharmaceuticals specified by the Department, based on a review of the PGRRP engineering report and the affected groundwater basin(s).” Although the regulations have not been finalized, many practitioners in California are establishing monitoring program for EDCs and PPCPs. It is likely that other regulatory agencies will adopt similar strategies in their own water recycling programs.

Regulatory Activities in Europe

In the early 1980s, the European Union (EU) Agency for the Evaluation of Medicinal Products began looking at veterinary PhACs and their metabolites with respect to releases into the environment and possible adverse impacts on ecological systems. In 1996, the European Committee for Veterinary Medicinal Products released its final guidance for risk assessments for veterinary medicinal products (Commission of the European Communities, 1999). This directive contained a phased approach that assesses potential for release of PhACs into the environment, evaluated possible fate and effects and looked
at effects on specific biota that might receive exposure. To date, no comparable EU regulations or guidelines have been established for human PhACs. In October 2002, Global Water Research Council (GWRC) held a workshop in South Africa with the intention of compiling a priority list of EDCs which would be representative of several EDC groups that commonly occur in aquatic systems (Water Research Commission, 2003a). The groups of chemicals included in the list were hormones, pesticides and herbicides, industrial chemicals like alkyl phenols, phthalates, and polychlorinated biphenyl compounds (PCBs), and heavy metals (Water Research Commission, 2003b). The participants at the workshop agreed on a EDC Priority List to be used in future joint activities (Water Research Commission, 2003c). However, the list is considered to be dynamic and compounds may be added to or deleted from the list as more information became available.

References


APPENDIX – B

WORKSHOP MATERIALS
AGENDA

“AwwaRF Endocrine Disrupting Chemicals (EDCs) and Pharmaceutical and Personal Care Products (PPCPs) Research Needs Workshop”
Marriott
4100 Admiralty Way
Marina del Rey, CA 90292
(310) 301-3000
Palisades Room
October 2 & 3, 2007

Objective: The goal of this workshop is to prepare a 5 Year Research Plan to identify and prioritize projects to focus on EDC and PPCP research gaps related to drinking water.

Day 1, October 2

1:00 – 1:15  Introduction
Rob Renner, Chris Rayburn, Misha Hasan

1:15 – 1:45  Introductions/agenda/approach  Ed Means

1:45 – 2:15  Overview of literature  Amlan Ghosh

2:15 – 3:15  Review of research ideas  Group

3:15 – 3:30  Break

3:30 – 4:00  Continue review of research ideas  Group

4:00 – 5:30  Identification of research areas/gaps  Group

5:30 – 6:00  Establish breakout groups/chairpersons
Review research template  Ed Means

6:00  Adjourn

7:00  Dinner - Location: To Be Announced
(meet in hotel lobby at 6:45)  Group
Day 2, October 3

7:15 – 8:00  Continental buffet breakfast – Location: ________

8:00 – 8:15  Review of Day 1/Day 2 approach – Location: _____  Ed Means

8:15 – 12:15  Write/polish project descriptions - Locations:______  Breakout

12:15 – 1:00  Lunch – Location: ________

1:00 – 2:00  Review budgets/schedule/priority  Breakout

2:00 – 3:30  Group report out on projects/funding level/priority
- Location: ______________  Spokespersons

3:30 – 3:45  Break

3:45 – 4:45  Group prioritization exercise – Location: ___  Group

4:45 - 5:00  Wrap up
- Ed Means
  Misha Hasan

5:00  Adjourn
American water works association
Research Foundation

Endocrine Disrupting Chemicals and
Pharmaceutical and Personal Care Products
Research Needs Workshop

October 2 & 3, 2007
Marina Del Rey, CA
### Workshop Agenda Day 1- October 2

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00 – 2:00</td>
<td>Introductions</td>
<td>Renner, Rayburn, Hasan, Means</td>
</tr>
<tr>
<td>2:00 – 2:30</td>
<td>Overview of literature</td>
<td>Ghosh</td>
</tr>
<tr>
<td>2:30 – 3:00</td>
<td>Review of research ideas</td>
<td>Group</td>
</tr>
<tr>
<td>3:00 – 3:15</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>3:15 – 4:15</td>
<td>Review of research ideas</td>
<td>Group</td>
</tr>
<tr>
<td>4:15 – 5:30</td>
<td>ID research areas/gaps</td>
<td>Group</td>
</tr>
<tr>
<td>5:30 – 6:00</td>
<td>Establish breakout groups/chair</td>
<td>Means</td>
</tr>
<tr>
<td>6:00</td>
<td>Adjourn</td>
<td></td>
</tr>
<tr>
<td>7:00</td>
<td>Dinner - (meet in hotel lobby at 6:45)</td>
<td></td>
</tr>
</tbody>
</table>

### Workshop Agenda - Day 2, October 3

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:15 – 8:00</td>
<td>Continental buffet breakfast</td>
<td></td>
</tr>
<tr>
<td>8:00 – 8:15</td>
<td>Review of Day 1/Day 2 approach</td>
<td>Means</td>
</tr>
<tr>
<td>8:15 – 12:15</td>
<td>Write/polish project abstracts</td>
<td>Breakout</td>
</tr>
<tr>
<td>12:15 – 1:00</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>1:00 – 2:00</td>
<td>Review budgets/schedule/priority</td>
<td>Breakout</td>
</tr>
<tr>
<td>2:00 – 3:30</td>
<td>Group reports projects/budget/priority</td>
<td>Spokespersons</td>
</tr>
</tbody>
</table>
Workshop Agenda - Day 2, October 3

3:30 – 3:45 Break
3:45 – 4:45 Group prioritization exercise Group
4:45 - 5:00 Wrap up Means/Hasan
5:00 Adjourn

Research Abstracts

END RESULT-
Breakout groups will refine/develop
Abstracts:
- research description
- priority
- budget &
- schedule
Group - compile projects into a research plan for AwwaRF consideration
Ranking Criteria

1. **Fills Critical Info Need** – Which projects would fill the greatest need? 1 = highest, 3 = lowest

2. **Likelihood for Success** - Is the project as defined likely to achieve the desired objectives (approach, budget, schedule, etc.)? 1 = highest, 3 = lowest

---

Group Worksheet

<table>
<thead>
<tr>
<th>Project ID #</th>
<th>Group Color</th>
<th>Project Description</th>
<th>Fills Critical Info Need (1-3)</th>
<th>Likelihood for Success (1-3)</th>
<th>Estimated Budget ($)</th>
<th>Estimated Project Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Project 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Project 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Project 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Workshop Agenda Day 1 - October 2

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00 – 2:00</td>
<td>Introductions</td>
<td>Renner, Rayburn, Hasan, Means</td>
</tr>
<tr>
<td>2:00 – 2:30</td>
<td>Overview of literature</td>
<td>Ghosh</td>
</tr>
<tr>
<td>2:30 – 3:00</td>
<td>Review of research ideas</td>
<td>Group</td>
</tr>
<tr>
<td>3:00 – 3:15</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>3:15 – 4:15</td>
<td>Review of research ideas</td>
<td>Group</td>
</tr>
<tr>
<td>4:15 – 5:30</td>
<td>ID research areas/gaps</td>
<td>Group</td>
</tr>
<tr>
<td>5:30 – 6:00</td>
<td>Establish breakout groups/chair</td>
<td>Means</td>
</tr>
<tr>
<td>6:00</td>
<td>Adjourn</td>
<td></td>
</tr>
<tr>
<td>7:00</td>
<td>Dinner - (meet in hotel lobby at 6:45)</td>
<td></td>
</tr>
</tbody>
</table>
Endocrine Disrupting Chemicals and Pharmaceutical and Personal Care Products Research Needs Workshop

Overview of Literature

October 2 & 3, 2007
Marina Del Rey, CA

Presentation Outline

- EDC/PPCP Background
- Source and Occurrence
- Toxicology and Health Effects
- Analysis Methods
- Drinking Water Treatment Processes
- Regulatory Status
- Research Needs?
**EDC/ PPCP Research - Global Perspective**

- Investigation of EDCs/ PPCPs as environmental pollutants first began in Europe in the 1970s

- With the advent of monitoring and research in the U.S., literature has grown exponentially since 2000

- EDCs/ PPCPs are not truly “emerging pollutants”. It is the understanding of the significance of their occurrence in the environment is beginning to develop.
  - However, the production of these compounds is increasing – estimated 1500 “new” antimicrobial products since 2000 (Halden, 2007)

- Topic has high public visibility – continues to attract significant media attention

*Adapted from Daughton presentation, 2006*

---

**EDC/ PPCP Research - Scope of Issue**

- Thousands of distinct entities of different chemical classes

- Large numbers possess very high biological activity

- For most classes, little is known about the potential for effects

- In general, EDCs/PPCPs are not regulated pollutants

*Adapted from Daughton presentation, 2006*
Endocrine Disrupting Chemicals

EDCs:
“Exogenous agents that interfere with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis, reproduction, development, and/or behavior” (EPA, 1997)

PhACs:
“Chemicals used for diagnosis, treatment (cure/mitigation), alteration or prevention of disease, health condition, or structure/function of the human body” (Daughton and Ternes, 1999)

EDC/PPCP Examples

<table>
<thead>
<tr>
<th>Compound Class</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile organics</td>
<td>1,1-DCA</td>
</tr>
<tr>
<td>Gasoline additives</td>
<td>MTBE, TBA</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>Antibiotics, drugs</td>
</tr>
<tr>
<td>Personal care products</td>
<td>Polycyclic musks</td>
</tr>
<tr>
<td>Disinfection byproducts</td>
<td>NDMA</td>
</tr>
<tr>
<td>Industrial additives</td>
<td>1,4-dioxane</td>
</tr>
<tr>
<td>Inorganics/explosives</td>
<td>Perchlorate, RDX</td>
</tr>
<tr>
<td>Pesticides/herbicides</td>
<td>Diazinon</td>
</tr>
<tr>
<td>Surfactants/residues</td>
<td>Alkylphenol polyethoxylates, triclosan</td>
</tr>
<tr>
<td>Persistent organic compounds</td>
<td>Polybrominated diphenyl ether (PBDEs) Perfluorinated octanoic acids (PFOAs)</td>
</tr>
</tbody>
</table>

Adapted from Reinhard/Giger, NRC, 1999
Sources of EDCs:
- Majority EDCs are introduced into the environment from man-made sources
  - Waste discharges from municipalities and industries
  - Agricultural and urban runoff
- EDCs can also occur naturally (e.g. phytoestrogens)

Monitoring Studies in the U.S.
- USGS 2002 (nationwide reconnaissance study)
  - 142 streams, 55 wells, and 7 effluent samples were analyzed across 36 states

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Use</th>
<th>Frequency of Detection (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coprostanol</td>
<td>Estrogen</td>
<td>~ 80%</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Plant/ Animal Steroid</td>
<td>~ 80%</td>
</tr>
<tr>
<td>N-N-diethyltoluamide</td>
<td>Mosquito Repellent</td>
<td>~ 80%</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Stimulant</td>
<td>~ 75%</td>
</tr>
<tr>
<td>Tris(2-chloroethyl)phosphate</td>
<td>Fire Retardant</td>
<td>~ 75%</td>
</tr>
<tr>
<td>Triclosan</td>
<td>Antibiotic</td>
<td>~ 60%</td>
</tr>
<tr>
<td>4-Nonylphenol</td>
<td>Surfactant</td>
<td>~ 60%</td>
</tr>
<tr>
<td>4-Nonylphenol monoethoxylate</td>
<td>Surfactant</td>
<td>~ 50%</td>
</tr>
</tbody>
</table>
Source and Occurrence

EDC Occurrence in Drinking Water

- Drinking water supplies at Cape Cod impacted by septic systems leakage of alkylphenol polyethoxylates (Rudel et al., 1998)

- Clofibric acid detected in drinking water in Berlin (Heberer and Stan, 1997)

- The detected EDCs/PPCPs probably represent but a small fraction of all those that actually occur

Environmental Fate and Transport

- Environmental fate & transport vary greatly by compound in question & environmental conditions (matrix, temp)

- Persistence in water and soil can vary from days to months
  - 17β-estradiol persists in water for less than a week
  - Endosulfan has an average half-life of 50 days in water (Ying et al., 2002)

- Environment mobility determined by sorption affinity on organic carbon ($K_{oc}$ values)

- EDCs are subject to differential biological metabolism which yields either bioactivation or bioinactivation

- Breakdown of EDC/PPCPs create degradates of these compounds – properties of which may be independent of the parent compound
Toxicity/ Health Effects

- >70 studies of endocrine effects of specific chemicals on birds, fish, mammals, & molluscs were published between 1970 and 1995 (Krimsky, 2000)
  - Developmental problems in alligators in Florida lakes (Guillette, 1995)
  - Abnormalities in male fish living in the effluents of wastewater treatment plants (Jobling and Sumpter, 1993)
  - Severe reproductive impairment in sheep grazing on certain strains of clover in New Zealand due to phytoestrogens (Adams, 1998)

Toxicity/ Health Effects

Human Health Effects

- Endocrine disruption in humans by environmental exposure to EDCs is still debatable (Safe and Gaido, 1998)
  - Endocrine disruption likely to be caused by EDCs present in food and drug sources compared to drinking water (concentrations orders of magnitude higher)
  - A mother’s consumption of Great Lakes fish with high PCB tissue levels was linked to impaired cognitive development in children (Jacobsen et al., 1996)
Toxicity/ Health Effects

Toxicological Issues

- Additive effects: Similar categories of EDCs interact with well-defined molecular targets – thus one agent can be replaced totally or in-part by an equi-effective concentration of another, without diminishing the overall combined effect (Kortenkamp, 2007)

- Interactive effects: Synergism is possible where combined action exceeds the sum of individual effects

- Very little research data is available on EDC effects at extremely low concentrations (nM-pM and below). Some agents have ability to impart previously unrecognized effects at “ultra-trace” concentrations (Daughton, 2006)

Analytical Methods

Most common analytical method for identification and quantification of EDCs/ PPCPs consists of:

- extraction of the chemicals from water
- concentration of the resulting extract
- chromatographic separation
- detection

- Several extraction techniques are available – solid-phase extraction is most commonly used
- Most commonly used analytical instruments –
  - Gas Chromatography (GC) and Liquid Chromatography (LC)
  - Detector – Mass Spectrometer (MS)
- Detection limits of most EDCs in water are in ng/L
**Bio-Analytical Methods**

- These methods employ a biological end point such as:
  - Receptor binding assays
  - Cellular bioassays
- Both *in vivo* and *in vitro* bioassays are used
- DNA microarrays have also been used for analysis of EDC concentration in water (Kullman et al., 2007)

**Drinking Water Treatment Processes**

- Several drinking water treatment processes can be effective
- EDC removal can occur by both physical and chemical removal processes

<table>
<thead>
<tr>
<th>Performance of Drinking Water Treatment Processes (KWR, 2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit Operation</strong></td>
</tr>
<tr>
<td>Activated Carbon</td>
</tr>
<tr>
<td>Ozonation/ Advanced Oxidation</td>
</tr>
<tr>
<td>UV</td>
</tr>
<tr>
<td>Cl₂/ClO₂</td>
</tr>
<tr>
<td>Softening/ Metal Oxide</td>
</tr>
<tr>
<td>Coagulation/ Flocculation</td>
</tr>
<tr>
<td>Nanofiltration</td>
</tr>
<tr>
<td>RO</td>
</tr>
</tbody>
</table>
Drinking Water Treatment Processes

Adsorption on Activated Carbon
- GAC/PAC demonstrated >75% removal of many EDCs (Westerhoff, 2003)
  - Removal of charged species - pH dependent
  - Very large molecules tend to have low removal due to steric hindrance

Ozone/ Advanced Oxidation
- Several EDCs were removed with ozone (Snyder et al., 2006)
  - Antibacterial substance, azithromycin reacted rapidly with ozone
  - Some compounds (e.g. clofibric acid) are not well removed by ozone

Drinking Water Treatment Processes

Membranes
- NF and RO processes can be very effective at EDC/PPCP removal (Snyder et al., 2007)
  - > 90% removal was observed for pharmaceuticals
  - Removal of charged species was better than that of neutral species for both RO and NF

Processes with limited success in EDC/PPCP removal:
- Coagulation/ Flocculation
- Chlorine
- Chlorine Dioxide
- UV
Regulatory History

- 1996: Amendments to FFDCA and SDWA
- EPA was mandated to develop a screening program to determine whether certain substances were EDCs
- 1998: EDSTAC was established and issued a final report outlining a conceptual framework for EDC screening
- 2001: EDMVS was formed and tasked with method validation

Regulations - Current Status

- Currently no federal regulations for EDCs/PPCPs in drinking or natural waters
- FDA requires ecological testing & evaluation of a pharmaceutical only if environmental concentration in water or soil is expected to exceed 1 µg/L or 100 µg/kg, respectively (FDA, 1998)
- In 2007, a first draft list of 73 pesticide active ingredients was prepared for screening (EPA, 2007)
- The State of California currently monitoring recycled water EDC/PPCPs and is considering regulations.
- Status of regulations in Europe similar to status in U.S.
Research Needs?
APPENDIX – C

PROJECT ABSTRACTS
PROJECT TITLE: PPCP and EDC Public Outreach Guidance for Water Providers

Background:
Water providers need current, understandable training regarding PPCPs/EDCs as increasingly important water quality concerns; they particularly need guidance in developing approaches for applying this information in assessing and addressing public awareness and perception issues. Although information on occurrence and health risk may represent a continuing challenge for many years, public perception issues are already of concern and effective outreach efforts are needed immediately to deal with apparent increases in public misunderstanding of relative risk, effective treatment, and source selection decisions. Expanded public outreach tools would appropriately reflect and build on current knowledge and research on assessing and understanding public perceptions, including projects such as the Comprehensive Utility Guide for Endocrine Disruptors and Pharmaceuticals in Drinking Water (#2033). The overall intent would be to identify optimal methods of providing information to water providers and the public, including consideration of methods and scope of effective educational resources and presentation avenues.

Objectives:
To develop PPCP/EDC training materials for water providers and guidance on effective public communication and outreach, including the media and other stakeholders.

Approach:
The Project Scope will include the following:
1. Review available knowledge and research outcomes to identify and, if possible, to recommend a public communication strategy which addresses PPCP/EDCs issues. Risk communication principles should be incorporated.
2. Develop guidance on application of public outreach approaches for water suppliers to deal with the public and the media, particularly regarding information about trace level substances in water for which health risk is uncertain. Consider treatment outreach, cost-benefit communications, source information and point of use treatment guidance. Consider Congressman Waxman’s committee concerns in development of the tools.
3. Conduct workshops including subject experts to develop and vet messages and communication tools.
4. Reflect consideration of tailoring public outreach to local or regional conditions for which political or environmental issues affect public perception, such as: media approaches; environmental group activities; local ordinances or other prohibitions on treatment and use of potable and reused supplies; contamination history effect on local communities; and other factors likely to require consideration in application of public outreach guidance through the use of case studies.
5. Assess cost and likely effectiveness (e.g. test messages in focus groups) of various types of information compilation and dissemination approaches to allow selection of effective training formats for water providers (printed materials, video disc or online presentations, etc.).
6. Recommend format and approaches to public outreach (including boards and commissions), such as direct mail, FAQs, pamphlets, internet, focus groups, public presentations, surveys, etc.
7. Provide messages and tools early in the project.
8. Develop an ongoing revision process to ensure periodic incorporation of new information and “lessons learned” into public outreach guidance.

**Recommended Budget:** Estimated project cost is $300,000

**Recommended Schedule:** 24 months

**Partners:**
WateReuse
WEF
WERF
Physicians/specialists
Academics
Abstract #2

PROJECT TITLE: Interim Water Utility Strategy for Responding to Emerging Contaminant Issues

Background:
Emerging contaminants, particularly Endocrine Disrupting Chemicals and Pharmaceuticals, are found in many water bodies used for water supply. There are clear evidences that these contaminants negatively impact aquatic organisms, even at extremely low level. While there is no consensus that these chemicals also impact human health in general and via water supply in particular, the public and the media are becoming increasingly concerned about this prospect and are looking to water utilities for assurance of high quality of their drinking water. Despite numerous investigations, the water industry lacks a clear consensus on and understanding of relevant issues, such as: identifying and monitoring ECs; feasibility and cost of their removal from water; legal implications of no action; a reliable alternative indicator to reduce monitoring needs and costs; etc. Given this lack of consensus, water utilities do not have a clear or consistent response for the questions and concerns of their customers and stakeholders. Therefore, there is a need for an industry-wide interim strategy that is based on current state of knowledge and best professional judgment and that could be used by water utilities to address their stakeholders’ concerns and justify their actions/no actions.

Objectives:
The objective of the project is to develop an interim strategy for responding to emerging contaminants challenges that would describe the best practices for water utilities to follow today given the existing knowledge on chemistry, occurrence, human health and environmental implications, feasibility and removal cost. The project would provide a framework for actions/no actions that can be taken now by water utilities in spite of the lack of scientific understanding/consensus and regulations. This framework would include recommendations for monitoring/analytical programs, treatment process evaluation and enhancement, source protection efforts, and risk communication with customers and media.

Current AwwaRF Project 4001 RFP will develop an overall risk communication strategy for water contaminants and individual contaminant tools to help utilities provide risk management information to customers and the public. Information developed from this project will be somewhat parallel to that effort except that it will utilize the existing knowledge and consider uncertainties and best professional judgment to provide a defensible framework for actions/no actions. This will be a good tool for the utilities to identify the next steps and justify why such an action (or no action) is taken.

Approach:
1. Review the literature related to best practices for managing uncertainty related to human or ecological impacts of emerging contaminant exposure.
2. Through workshops identify and frame key strategic actions/initiatives and guidance related to best practices for managing the perceived or actual risks associated with emerging contaminants.
3. Formulate and gain consensus on strategies and specific actions to be taken by the public water supply community to effectively position utilities to inform the public.

**Recommended Budget:** $150,000

**Recommended Schedule:** 1 year
Abstract # 3

PROJECT TITLE: “Information Database for Compounds of Potential Concern”

Background:

Multiple drivers impact a drinking water utility’s need for addressing compounds of potential concern (CPCs; also referred to as Emerging Chemical Contaminants), including the potential for impacts on public health and the environment, existing and potential future treatment schemes, public perception, impending and potential future regulations, economic considerations, and more. Examples of chemicals that may be considered CPCs include endocrine disrupting compounds (EDCs), pharmaceutically-active compounds (PhACs), personal care products (PCPs), detergents, plasticizers, pesticides and their degradates, algal toxins, and others. Typically CPCs are not already regulated, but in some cases certain regulations may be applicable (e.g., the USEPA Contaminant Candidate List and the USEPA Unregulated Contaminant Monitoring Rule).

The existing limitations in knowledge about the subject, as well as limitations in existing data for the occurrence of these chemicals in specific source waters and the vast number of potential compounds that could be considered, make it difficult for drinking water suppliers to know what unregulated chemicals, and at what levels, they should be concerned about and direct their efforts toward.

One possible strategy to respond proactively to this challenge is to develop a database that includes key information related to numerous CPCs. The database could be used by water utilities to help identify data and information gaps, determine what further efforts may be warranted, and/or help answer questions as they arise. Additional efforts by a utility may include development of future monitoring programs, treatment studies, source water protection activities, and other potential measures.

Objectives:

1. Develop an electronic database for water utilities to use that provides relevant information about CPCs, including physicochemical properties, uses, sources, classification, analytical methods, available laboratories, source water occurrence information, treatment data, health effects (human and perhaps environmental), relative exposure to human populations from different environmental sources (drinking water compared to other environmental sources), related regulations, and a listing of the references used.

2. Include a description of how the database was developed and how it can best be used by a water utility.

3. Final deliverables would include the electronic database and a final report summarizing how the database was developed.

Approach:

The objectives listed above largely outline the overall approach to be used. In addition, the contractor should identify and review relevant information sources, including information available through the USGS, USEPA, AWWA, AwwaRF, WERF, and other similar organizations. The database should include a means to incorporate future updates of information (i.e., the system developed will be able to be updated easily...
and continuously as new information becomes available). Future new sources of information could include significant advances in the identification of new CPCs or improved knowledge of potential health effects of CPCs already in the database, as well as new analytical methods, occurrence studies, and treatment studies.

Consider a “Wikipedia” style self updating database. The Database design considerations include a user-friendly interface, ease of maintenance, and an ability to continuously update it as new information becomes available. The database would preferably be developed using MS Access software or some other equivalent.

Contractor will establish formal requirements for the database through a stakeholder process.

Suggestions for ongoing maintenance/ownership should be included.

**Recommended Budget:** $150,000

**Recommended Schedule:** 1 year
PROJECT TITLE: Developing Practical Health Advice as Context for Contaminant Risk Communication

Background:
There is a strong symbolic significance to drinking water and to water purity. As a consequence a number of health questions are often posed to water agencies. These inquiries about water are an entry point for discussions about health. Rather than only responding to particular drinking water concerns, it could be of better public service, especially considering peoples limited attention-processing capacity, to address the underlying concern. For example, a question on a specific contaminant that might cause birth defects underscores a concern for a safe pregnancy. The information resources to not only respond to the particular question (the focus of many utility efforts to produce fact sheets), but on best preventative practice for that health endpoint might be of great public service.

Objectives:
Determine whether response to underlying concerns about particular contaminants is an effective, complementary risk communication strategy.

If so, obtain broad integrative guidance from trusted public health resources. For example, the National Institutes of Health and the National Center for Infectious Diseases provided guidance for reducing the risk for opportunistic infections amongst immunocompromised individuals. The guidance addressed various exposure routes (e.g., people, pets, food, water, air, etc). It can be found at: http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5108a2.htm. Such integrative pieces may greatly assist risk communication strategies by water agencies.

Approach:
1. Compare sample risk communication pieces focused on particular EDCs and other compounds with risk communication pieces focused on underlying concerns (e.g., how to increase chances of having a healthy baby) in focus groups.

Consider the question: do THMs cause birth defects (or miscarriage)? The answers a water agency will often provide is we currently meet all regulations, there were limitations associated with studies exposure assessment, there may or may not be a risk. Yet a complimentary response would be: You are keenly interested in the safety of your child: you want to know what can I do to have a safe pregnancy? Here are some of the key actions the American College of Ob-Gyn has recommended for reducing your risk (e.g., stop pumping your own gas, take foliate supplements, etc.).

2. If response is positive, AWWARF, AWWA, AMWA should leverage its collective influence to encourage such integrative pieces through EPA, NIH, NRC, NIEHS, etc.
**Recommended Budget:** $200k plus programmatic budgeting by each organization – no additional extra-mural budget required. May need congressional charge and/or earmarks for work.

**Recommended Schedule:** 24 months
Abstract #5

**PROJECT TITLE:** Strategy for Developing Alliances to Effectively Manage the Complexities Associated With EDCs/PPCPs.

**Background:**
There is a need to develop a strategy to engage appropriate stakeholders in the discussion related to source control, risk management, risk communication, political, research community, academics, industry, data sharing, legal, etc. to effectively manage the complexities associated with EDCs/PPCPs.

**Objectives:**
To develop a strategic plan for developing alliances.

**Approach:**
The Project Scope will include the following:
1. Identify stakeholders and opinion leaders.
2. Conduct workshops to identify the goals, objectives, strategies and actions.
3. Leverage the AwwaRF Watershed stakeholder project
4. Develop the strategic plan.

**Recommended Budget:** Estimated project cost is $300,000

**Recommended Schedule:** 24 months

**Partners:**
WERF
WUC
Industry (Pharmaceutical)
Agriculture
FDA
USDA
(Ask Karen Blackburn re: Fragrance Manufactures?)
PROJECT TITLE: Addressing Impacts Related to Expanded Wastewater Discharge and Reuse on Source Water Quality and Perception

Background:
Wastewater discharges and recycled water use are an increasing fraction of water supply in the U.S. The public concerns associated with this will likely increase. Addressing these concerns will be important.

Objectives:
Understand the implications of increased wastewater and recycled water discharge/use on drinking water quality and develop management strategies and public outreach tools.

Approach:
The Project Scope will include the following:
1. Quantify/project source water quality impacts of expanded wastewater discharge and reuse through hypothetical scenarios that represent a range of plausible conditions, hydrologies, geographies, etc.
2. Illustrate potential impacts utilities should consider in their facility planning and communications programs.
3. Prepare an issue paper.

Recommended Budget: Estimated project cost is $100,000

Recommended Schedule: 12 months

Partners:
WateReuse Foundation
Abstract # 7

**PROJECT TITLE:** A prioritization scheme that will help design future environmental research on naturally occurring and synthetic contaminants that are potential endocrine disruptors (EDs) related to human health.

**Background:**
Many compendiums, journal articles, and books summarize the ED and Pharmaceuticals and Personal Care Product (PPCP) effects of a range of natural and synthetic contaminants. A scheme is needed to prioritize these contaminants for additional laboratory methods development and environmental research based on the needs of the drinking water community. Existing prioritization schemes and related activities for water contaminants include work on high production volume chemicals as potential environmental contaminants, Food and Drug Administration requirements for estimating the potential environmental occurrence of new drugs, the Environmental Protection Agency requirements for estimating the potential for environmental occurrence of new pesticides, and the EPA’s drinking water Contaminant Candidate List. However, none of these existing activities focus entirely on the unique aspects of many EDs and PPCPs such as their potential potencies at low concentrations, relatively low production volumes (as compared to other HPV chemicals), and ubiquitous use in animal and human therapies. Consequently, there are no comprehensive and consensus based prioritization schemes for EDs and PPCPs specifically created to help meet the environmental research needs of the drinking water community.

**Objectives:**
Develop a consensus-based objective prioritization scheme for EDs and PPCPs to help meet the environmental research needs of the drinking water community.

**Approach:**
Conduct a literature review of all existing related schemes and data. Develop a draft objective, transparent, and reproducible (to the extent possible) prioritization scheme based on the combined influences of environmental occurrence and potential human-health impacts of known, or suspected endocrine disrupting compounds. Include data and information that would lend itself to clear distinguishing factors in the rating scheme such as: 1) distinctions among those compounds most likely to occur in water vs those more likely found sorbed to environmental solids, 2) distinctions between those compounds likely to degrade in the environment vs those more persistent, 3) sources and source pathways of the compounds and related likelihood and locations of their introduction to the environment, 4) potency of the contaminant, 5) distinguish among the different endocrine system functions impacted (e.g. stress vs thyroid vs reproductive, etc.), 6) potential modes of action, and 7) likely health endpoint. Develop preliminary prioritization scheme, conduct test with subset of data, hold second workshop for presentation of preliminary prioritization scheme and revise as recommended. Hold a workshop of key experts in the drinking water, human health, and environmental sciences in order to derive consensus on the draft prioritization scheme. Note that water
treatment is not part of the considerations for this prioritization process as the focus is on environmental (source) waters.

**Recommended Budget:** Year one: $200,000

**Recommended Schedule:** Year one: Conduct literature review and workshop to vet straw prioritization scheme. Publish report.

**Partners:**
WERF
WateReuse
GWRC
Pharma et al.
PROJECT TITLE: Evaluation of GAC for Control of EDCs and PPCPs in Drinking Water

Background:
Adsorption of synthetic organic chemicals from water using activated carbon is recognized by USEPA as “Best Available Technology” for removal of many regulated organic contaminants. Early studies by the water industry looked at removal of disinfection by-products and removal of naturally occurring taste and odor compounds. Completed research also includes removal of pesticides and herbicides and a number of synthetic industrial chemicals by activated carbon. Based on previous research, it is expected that many of the EDCs/PPCPs detected in water supplies will be amenable to activated carbon adsorption.

Granular activated carbon (GAC) has been used by many water utilities for removal of disinfection by-product precursors, total organic carbon (TOC), and taste and odor producing compounds. The efficiency of activated carbon adsorption is affected by:
- The properties of the activated carbon itself
- The contact time of the water with the activated carbon (in the GAC bed)
- Number and characteristics of the organic chemicals
- Water temperature
- pH, alkalinity
- The concentration of inorganic substances in the water
- The concentration of natural organic matter in the water which competes for adsorption sites, thereby reducing the adsorption capacity for the target organic chemicals to be removed
- The presence or absence of chlorine in the water

In the case of EDC/PPCP removal, type, concentration, and mixture of EDCs and PPCPs are very important and could significantly impact the effective carbon usage rate. This complicates the evaluation of the applicability of GAC for removing EDCs and PPCPs from drinking water. More information is needed on the effectiveness and design and operating parameters for using GAC to remove EDCs/PPCPs for utilities to adequately evaluate the application of GAC.

Objectives:
The major objectives of the project are to:
1. Determine the effectiveness of GAC for removing mixtures of EDCs and PPCPs typically detected in surface water supplies.
2. Determine the design and operating conditions for obtaining the maximum removals and maximum use of the GAC.

Approach:
The overall approach to the project will include bench-scale testing of GAC using Rapid Small Scale Column Tests (RSSCT) to obtain the desired information. Pilot-scale studies might be conducted at selected sites to confirm the results of the bench-scale tests. The tests will be conducted on a variety of waters to capture a wide range of water
quality conditions including pH, alkalinity, and TOC. Water samples will be collected from full-scale water treatment facilities to represent realistic background metrics of water conditions. Variables to be tested include type of GAC, empty bed contact time, and loading rate. The final product will provide utilities with GAC removal and design and operating conditions that provide optimum removal of EDCs/PPCPs from their water supplies.

**Recommended Budget:** Total project cost is $400,000.

**Recommended Schedule:** 24 months
Abstract #9

PROJECT TITLE: Quantitative Structure Property Relationships (QSPR) to Predict Removal of PPCPs/EDCs in Water Treatment Processes

Background:
The use of drinking water sources impacted by wastewater discharge has raised public concerns due to the presence of trace organic contaminants in drinking water sources, where some compounds, such as endocrine disrupting compounds (EDCs), have been found to cause reproductive disorders in aquatic wildlife. Conventional water treatment processes employing coagulation/flocculation and filtration are rather ineffective in removing EDCs and pharmaceuticals and personal care products (PPCPs) from water. Chlorination has been shown to be effective at removing some EDCs and PPCPs and various advanced treatment processes, such as ozone, advanced oxidation processes, granular activated carbon, membranes, can achieve higher removal of the majority of EDCs and PPCPs. However, the near impossibility of experimentally studying the fate and transport of current and future emerging contaminants on an individual basis indicates a need to develop a set of tools which quickly provides guidance on how effectively certain compounds can be removed during drinking water treatment processes. These tools would provide utilities the ability to quickly screen an organic compound of concern and provide a meaningful response in regards to the fate of the compound and, if needed, provide the degree of treatment upgrade required for removal or recommend source control. Quantitative structure property relationships (QSPRs) are useful and powerful tools for quickly screening the environmental fate of emerging contaminants, and a priori, assessing their removal within treatment systems. These QSPR techniques would not be limited to emerging contaminants and can also be applied to any organic micropollutant of concern.

The concept of QSPR analysis is to mathematically, usually empirically, quantify the correlations between a fate parameter (e.g., degradation rate constant; partitioning coefficient) and molecular descriptors of a compound (e.g., volume, connectivity indices, dipole moment). Once a correlation is found, the treatability of emerging and current organic contaminants can be predicted using mechanistic and mass balance models. Molecular descriptors have been classically derived from the 2D structure (e.g., pKa, log Kow, connectivity indices, group contribution methods), but novel molecular descriptors can be derived from the 3D structure, such as quantum-mechanical and chemical descriptors (e.g., dipole moment, orbital energies). Nowadays, 3D-based molecular descriptors can be calculated relatively quickly due to the recent advancement of computational hardware and semi-empirical methods. Thus, 3D-based molecular descriptors are an attractive source for novel molecular descriptors that take into account all the electronic and geometrical interactions within a molecule, thus making QSPR analysis having a much broader scope and an enormous potential for predicting the removal or fate of individual compounds through water treatment systems.

Objectives:
The objectives of this proposed research is to 1) evaluate existing QSPRs for predicting kinetic rate constants by chlorine, chlorine dioxide, chloramine, ozone, and
AOP disinfection processes, membrane rejection parameters (e.g. orientation angle), activated-carbon adsorption partitioning coefficients, and 2) develop QSPRs where needed. These QSPR techniques can be used in process models to predict the behavior of emerging contaminants during various conventional and advanced drinking water treatment processes.

**Approach:**

The Project Scope will include the following:

1. Apply existing QSPR models to predict compound specific parameters for oxidation, sorption and membrane based processes. Compare predicted values against literature data for different classes of PPCPs/EDCs.

2. For compound classes that exhibit poor predictions, modify existing models using data from controlled experiments targeted to PPCPs/EDCs.

3. Apply QSPR models output parameters to existing process models for oxidation, sorption and membrane processes to predict PPCPs/EDCs removal under typical water treatment conditions.

**Recommended Budget:** Total Project cost is $625,000 with $500,000 requested from AwwaRF.

**Recommended Schedule:** 36 months
PROJECT TITLE: Removal Kinetics of PPCPs/EDCs using Disinfection Processes

Background:

The use of drinking water sources impacted by wastewater has raised public concerns due to the presence of trace organic contaminants in drinking water sources, where some compounds, such as endocrine disrupting compounds (EDCs), have been found to cause reproductive disorders in aquatic wildlife. Conventional water treatment processes employing coagulation/flocculation and filtration are rather ineffective in removing EDCs and pharmaceuticals and personal care products (PPCPs) from water. However, disinfection processes, such as chlorination and chloramination, have been shown to be effective at removing some EDCs and PPCPs (AwwaRF 2758). EDCs and PPCPs containing reactive functional groups are more amendable to oxidation by chlorine and chloramines where free chlorine tends to remove more compounds than chloramines. A few studies examined the effectiveness of chlorine dioxide on the removal of EDCs and PPCPs and showed that chlorine dioxide is better than chlorine in the oxidation of a select few of EDCs and PPCPs. These disinfection practices are currently employed in the majority of utilities across the U.S. and can be considered the first and ONLY treatment barrier to EDCs/PPCPs in present day conventional drinking water treatment systems. However, there is a lack of understanding on the impacts of typical drinking water quality and operational parameters on the removal kinetics of these compounds during chlorination, chloramination, chlorine dioxide, and ozone oxidation.

Water quality parameters, such as bromide concentration, organic carbon concentration, pH and temperature, and operational parameters, such as chlorine dose and contact time, can have an impact on the removal of EDCs and PPCPs. The chlorination of groundwaters containing high bromide will produce hypobromous acid, which in turn can react differently and/or at different rates with the organic compounds in question. Chlorination pH conditions within drinking water treatment plants can range between 6 to 10. Many of these emerging EDCs and PPCPs can be protonated or deprotonated depending on the pH, which can affect their amenability to oxidation. Also, the disinfection oxidation potential is affected by pH, such as chlorine (pKa 7.5), where HOCl is a stronger oxidizing and substituting agent than OCl-. The temperatures conditions during disinfection across geographical regions and seasons can range between near freezing to the mid 30s (°C), which can affect the removal of these compounds. Previous studies (AwwaRF 2758) have examined the removal of EDCs and PPCPs at long chlorine contact times (days) that resemble distribution residence times, however some plants utilize chlorine and chlorine dioxide just within the plant, which resemble contact times on the order of minutes to hours. This bodes the question, are the EDCs and PPCPs sufficiently removed at these shorter contact times? Also, how do sequencing disinfection schemes, such as chlorine/chloramines, chlorine dioxide/chloramines, chlorine dioxide/chlorine/chloramine, affect the overall removal of the EDCs and PPCPs?

Objectives:
The objectives of this proposed research are to 1) assess the impact of water quality (bromide concentration, organic carbon concentration, pH and temperature) and operational parameters (chlorine dose and contact time) on the removal kinetics of EDCs and PPCPs; 2) assess the effect of sequencing disinfection schemes (chlorine/chloramines, chlorine dioxide/chloramines, chlorine dioxide/chlorine/chloramines, ozone/chlorine) on the removal of the EDCs and PPCPs; and 3) recommend practical disinfection conditions and practices in order to optimize the removal of these organic contaminants during disinfection.

**Approach:**

The Project Scope will include the following:

1. Perform a comprehensive literature search on removal kinetics of EDCs and PPCPs by chlorine, chloramines, chlorine dioxide, and ozone.
2. Perform laboratory-scale studies to assess the impacts of water quality and operational parameters on the removal kinetics of EDCs and PPCPs by chlorine, chloramines, chlorine dioxide, and ozone. Various real water matrices should be examined that represent different water qualities used across the U.S. (e.g., groundwater vs. surface water).
3. Perform laboratory-scale studies to assess the effects of sequencing disinfection schemes (chlorine/chloramines, chlorine dioxide/chloramines, chlorine dioxide/chlorine/chloramines, ozone/chlorine) on the removal of EDCs and PPCPs.
4. Recommend disinfection conditions and practices that are best for the removal of these organic contaminants during conventional disinfection without compromising the primary disinfection goal of inactivating pathogens.

**Recommended Budget:** Total Project cost is $400,000 with $300,000 requested from AwwaRF.

**Recommended Schedule:** 30-36 months
PROJECT TITLE: Evaluation of the Potential for Toxic By-Products Formation during AOP Treatment of PPCPs and EDCs in Drinking Water Sources

Background:
While AOP is recognized as an effective means of degrading PPCPs and EDCs, the oxidation mechanism are not well understood. As a result, a number of oxidation reaction by-products with unknown toxicities and concentrations are potentially added to the drinking water. Some of these metabolites have been determined to have more significant health effects than their parent chemicals. This increases the risks associated with the use of this technology in many water treatment plants where the process has not been optimized for PPCPs and EDCs degradation and removal.

The present proposal is to identify the AOP by-products resulting from, but not limited to AOP processes such as ozonation, hydrogen peroxide oxidation, and UV. The outcomes of this project will guide the water treatment plants that might consider AOP to eliminate PPCPs and EDCs from their drinking waters.

Objectives:
The main objective of the project is to investigate the formation of AOP by-products formed during the removal of PPCPs and EDCs.

Approach:
1. Bench-scale study to characterize the by-products of the oxidation reactions between AOP and selected PPCPs and EDCs.
2. Investigate the effects of selected critical water and operating parameters on the formation of oxidation by-products.
3. Verify the findings of the bench-scale experiments in a pilot-plant environment.
4. Determine the optimum operating conditions for oxidation of PPCPs and EDCs to minimize formation of by-products.

Recommended Budget: Total project cost is $600,000. Required funding is $400,000.

Recommended Schedule: 3 years.
PROJECT TITLE: Transformation of pharmaceutically-active compounds (PhACs) by chemical disinfectants to toxic or odoriferous products

Background:
It has been demonstrated that numerous PhACs are removed during drinking water treatment. However, little effort has been made to identify the products of these reactions or their potential human health effects. From the limited available data, there is evidence that some transformation products are more toxic than their parent compound (e.g., NAPQI and benzoquinone from chlorination of acetaminophen) and that toxic disinfection byproducts are formed during disinfection (e.g., NDMA can be formed with a yield during chlorination and ozonation of PhACs and pesticides). Furthermore, transformation of certain compounds also could result in production of compounds with low odor thresholds within the distribution system.

Objectives:
Assess significance of transformation products of PhACs on finished drinking water quality. Identify specific PhACs and common structural attributes that lead to formation of toxic or odoriferous products. Examples of toxic compounds to be considered include potent halogenated and nitrogenous DBPs and activated metabolites). Examples of odoriferous compounds include halogenated phenols and anisoles.

Approach:
In general, concentrations of PhACs in drinking water sources are relatively low (i.e., < 1 g/L). Therefore, research should focus on compounds that pose concerns at low concentrations.
1. Literature review: Summarizes cases in which toxic or odoriferous compounds have been detected upon addition of chemical disinfectants to PhACs. Identify compounds that are known to be toxic or pose aesthetic concerns at extremely low levels. Identify appropriate analytical methods. Develop a short list of compounds to be considered in experimental phase of project.
2. Conduct laboratory studies using chemical disinfectants (e.g., chlorine, chloramines and possibly ozone) and PhACs that have the potential to form products from the short list. Experiments can involve pure compounds or wastewater-impacted source waters. Experiments with wastewater-impacted waters must consider the importance of precursors other than PhACs.
3. Assess magnitude of issue of to water industry.

Recommended Budget: Total Project cost is $325,000. Requested funding is $250,000 with match funding of $75,000.

Recommended Schedule: 24 months
Abstract #13

PROJECT TITLE: Removal of EDCs and PPCPs by Natural Attenuation in Surface Waters

Background:
Many of the EDCs and PPCPs discharged by wastewater treatment plants can be removed in surface waters by processes such as biotransformation, sorption and photolysis. As a result, surface waters can be considered as one of the multiple barriers that is part of the continuum of treatment process from the sources to the consumer of drinking water. To understand the potential for removal and to predict the removal of compounds in surface waters, additional information is needed on the individual removal mechanisms and the effect of surface water conditions on removal rates. Ultimately, this understanding may be useful in the development of approaches for augmenting contaminant removal (e.g., constructed wetlands) and understanding the effects of changing conditions on natural attenuation (e.g., how will control of eutrophication affect contaminant removal rates?)

Objectives:
Evaluate the overall importance of natural attenuation in removing EDCs and PPCPs that could be present in source water and to develop a better understanding of factors controlling different mechanisms of natural attenuation.

Approach:
Assessment of natural attenuation in surface waters is complicated by temporal fluctuations in the concentrations of contaminants and difficulties associated with quantification of low concentrations of compounds. Therefore, the project will focus on evaluation of the rates and mechanisms of processes in laboratory and pilot-scale systems.

1. Laboratory Experiments to evaluate biotransformation, sorption and photolysis under laboratory conditions that approximate conditions encountered in surface waters.
   a. Biotransformation experiments: Factors to be considered include the source of the indigenous microbial community, the source of labile organic carbon and the redox conditions.
   b. Sorption: Experiments should consider the importance of bed sediments and suspended sediments originating from different sources (e.g., different organic carbon content). The role of macrophytes should also be considered.
   c. Photolysis: Experiments should consider direct and indirect photolysis during sunlight irradiation as well as the effects of different chromophores in surface waters.

2. Pilot-Scale Experiments: Evaluate the removal of selected compounds of concern in pilot-scale systems that capture the simultaneous occurrence of different removal mechanisms in surface waters. Appropriate pilot-scale facilities include surface water mesocosms, pilot-scale engineered wetlands and flowing
mesocosms (e.g., stream mesocosms). Consider the effects of seasonal variations in system performance and carbon loading on the system. Monitor the effects of water quality parameters on contaminant removal and other important aspects of drinking water quality (e.g., nitrate, disinfection byproduct precursors).

3. Synthesis of results: Assess the overall importance of natural attenuation to contaminant removal in surface waters. Integrate results into water quality models and compare results with available monitoring data. Identify approaches for improving the removal of EDCs and PPCPs in surface waters.

**Recommended Budget:** Total Project cost is $450,000. Requested funding is $325,000 with match funding of $125,000.

**Recommended Schedule:** 36 months

**Partners:**
WERF
WateReuse
Abstract #14

PROJECT TITLE: Impact of Nanomaterials in Source Waters on the Fate and Transport of EDCs and PhACs through Drinking Water Treatment Processes

Description of Issue:

Nanomaterials (broadly classified as particles having at least one spatial dimension in the range of 1 nm to 100 nm) of varying chemical composition and morphology are increasingly being used in personal care products, industrial applications, and as a byproduct of several industrial processes. Several species of nanoparticles have been used as a drug delivery mechanism in order to target specific tissues/organs, to control the release of the drug in the body, and/or to facilitate passage of the drug through the digestive tract without being changed by the harsh environment therein. It has been well documented that natural colloidal organic matter can change the partitioning of aquatic endocrine disrupting compounds (EDCs) and pharmaceutically active substances (PhACs), but it is unclear whether nanoparticles will interact with such micropollutants in the same manner and what the net impact will be on the fate of such pollutants. Early indications are, however, that carbon-based nanomaterials may provide an ideal substrate for sorption of organic compounds in the aqueous phase. With the increased use and likelihood of environmental release of nanomaterials (especially for communities with wastewater-impacted source waters) and the potential changes in partitioning behavior, reactivity, and biological availability (both to microbes prior to treatment and to the consumer of the finished water) of PhACs and EDCs associated with nanomaterials, the impact of nanomaterials on the treatment, removal, and bioavailability of through drinking water treatment needs to be further evaluated.

It is critical that researchers and the water industry take a proactive approach to understanding the potential health and treatment impacts of emerging technologies and, in the case of nanomaterials, emerging contaminants. The potential impacts of nanomaterials are far reaching, but getting an early handle on immediate needs can help utilities and engineers decide whether additional or altered stages of treatment would be required to remove nanomaterials (and their associated co-contaminants) to improve the quality and safety of the finished drinking water.

Objectives:

1. Develop and validate techniques for measuring the concentration of specific PhACs and/or EDCs associated with nanomaterials.
2. Examine the change in transformation/degradation kinetics of PhACs and EDCs associated with colloidal nanomaterials.
3. Evaluate the transport of PhACs and EDCs associated with nanomaterials through laboratory and/or pilot scale drinking water treatment processes.

Approach:

1. Determine occurrence of engineered nanoparticles (i.e., fullerenes) in raw drinking water to assess relevance of potential changes of PPCPs/EDCs through partitioning into nanoparticles (as Phase 1 study)
Recommended Budget: $150,000

Recommended Schedule: 12 months
PROJECT TITLE: Removal of EDCs/PPCPs from drinking water using point of use devices

Background:
As water utilities respond to their stakeholder demands to make EDC/PPCP-free water available for drinking, performance information about point of use (POU) devices will be useful. Public fear of trace contaminants poses a genuine threat to water sustainability. The implementation of advanced processes such as RO and AOP are not economically viable for many utilities. Moreover, the loss of water resources through RO brine are not acceptable in many arid communities. It is more sensible to consider providing communities with tested POU devices then to implement large infrastructure changes. With new developments in analytical testing, it is clear than many new contaminants will be discovered and diminishingly minute concentrations. POU devices for the removal of ng/L concentrations of EDCs/PPCPs could provide cost effective trace contaminant removal without large infrastructure and operational costs. Beyond EDCs and pharmaceuticals, certain POU devices could provide ancillary benefit in the removal of regulated DBPs and yet identified emerging contaminants.

Objectives:
To determine effectiveness of a variety of commercially available POU devices for removing trace EDCs and PPCPs from finished drinking water. To determine the cost savings of providing effective POU devices to a community in lieu of infrastructure modifications and subsequent operational costs to entire system.

Approach:
The Project Scope will include the following:
1. Conduct public surveys to gauge the interest in using POU devices provided by the local water agency as compared to rate increases to substantiate large-scale infrastructure changes.
2. Evaluate several multi-barrier POU devices for the removal of broad classes of EDCs/PPCPs and other unregulated contaminants (i.e., NDMA, perchlorate, perfluorinated organics, and total organic halides).
3. Determine cost structure for providing and services POU devices versus an equivalent treatment scheme for a municipal large-scale water treatment plant. The public surveys and POU testing period will be approximately 12 months. Cost structure evaluations will require approximately three months.

Recommended Budget: Total Project cost is $250,000.

Recommended Schedule: 24 months total
PROJECT TITLE: Guidance Manual for Treatment Strategy Development

Background:
Water utilities are going to seek guidance to develop strategies to address the EDC/PPCP water quality issues. A number of research projects have been conducted or are currently underway or in planning to evaluate the efficiency of water treatment processes to remove EDCs/PPCPs from drinking water sources. There is going to be a need to consolidate this information into a guidance manual to develop industry benchmarks that utilities can use as they develop their strategies. One strategy is the removal of EDCs/PPCPs at the water treatment plant using industry benchmarks that include, but not be limited to, process removal efficiency, process design parameters, and operating conditions for unit or combinations (hybrid) of processes. Another control strategy would be an overall watershed assessment that includes not only the water treatment plant but also any wastewater discharges upstream of the water treatment plant intake.

Objectives:
The overall objective of this project is to prepare a guidance manual that utilities can use as they seek to develop strategies to control EDCs/PPCPs detected in their drinking water supplies.

Approach:
The project scope will include:
1. Consolidation of existing research information on the removal efficiencies of various treatment processes.
2. Summarize design and operating criteria for optimum removal of EDCs/PPCPs.
3. Develop tools for evaluating sustainability and carbon and energy footprints of various options that include, but are not limited to, EDC/PPCP removal at water treatment plants versus removal at wastewater treatment plants.
4. Review of existing regulatory structure relative to water and wastewater permitting.

Recommended Budget: Total project cost is $400,000.

Recommended Schedule: 24 months
Abstract #17

PROJECT TITLE: Occurrence, Fate and Transport of Endocrine Disrupting Chemicals (EDCs) and Personal Care Products (PPCPs) in Surface Water Representative Case Studies.

Background:
Recent studies have reported the occurrence worldwide of a vast array of EDCs and PPCPs in wastewater effluents and in surface waters impacted by treated wastewater discharges. The impact from treated wastewater on the quality of surface water will only increase with population growth and increasing agricultural and industrial development. Furthermore, increasing water demand and drought has resulted in an increase in water recycling and reuse. Currently, the numbers and types of EDCs and PPCPs occurring in a large number of watersheds are only partly known, and the trends, fate and transport are not fully established. A synoptic survey following “plugs” of water from wastewater discharging points through watersheds representing different geographical regions will provide valuable information on natural attention, fate and transport of EDCs and PPCPs. This data can be used to direct source water protection strategies designed to minimize potential endocrine disruption in sources of drinking water.

Objectives:
To determine the occurrence, fate and transport of EDCs and PPCPs from sources of wastewater input through watersheds representing different regions in the United States. This study could also utilize some identified compounds as tracers to assess the extent to which treated waste water is reaching downstream drinking water supplies.

Approach:
The Project Scope will include the following:
- Review of literature
  - occurrence of EDCs and PPCPs in wastewater and source water
  - fate and transport data when available
- Determine appropriate analyte list based on literature review
  - Include representative EDCs and PPCPs
  - Include some EDCs and PPCPs that are known to undergo photolysis, some that are biodegradable and some that are recalcitrant as possible tracers
- Develop sampling plan
  - representative geographical regions
  - identify wastewater treatment plants and downstream sampling points in the same watershed
  - include locations upstream of wastewater impact where possible
  - identify intakes for downstream drinking water treatment plants in the same watershed
- Analytical data collection and analysis
  - Samples will be collected seasonally (e.g., wet and dry seasons) for 1 year to capture seasonal variations in occurrence and fate and transport
**Recommended Budget:** Total Project cost is $600,000. Requested funding is $420,000 with $180,000 in-kind contributions.

**Recommended Schedule:** 24 – 30 months

**Partners:**
Metropolitan Water District of Southern California
USGS
Abstract #18

**PROJECT TITLE:** Characterization of Source Water Quality, Finished Water Quality, and Treatment Process Effectiveness Related to EDCs and PPCPs

**Background:**
The increasing production and consumption of endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) has led to a growing concern about the occurrence and fate of these compounds in the aquatic environment. A variety of EDCs and PPCPs have been detected in both surface and ground water supplies around the world. Although in many instances the concentrations are very low, a variety of compounds have been detected. Past research studies have shown that existing treatment processes have varying degrees of efficiencies in removing EDCs and PPCPs from drinking water. Conventional processes such as clarification, filtration, and disinfection have demonstrated limited removals of these compounds. Advanced processes such as GAC, advanced oxidation (ozone or UV with hydrogen peroxide), and membranes have demonstrated good to excellent removals depending on the compound. Much of the treatment information is from bench-scale studies, while only recently has there been research conducted on full-scale treatment processes. A national perspective on the occurrence and range of concentrations of EDCs and PPCPs in finished drinking waters will aid in understanding the risk assessment of exposure to consumers.

One recent KIWA study in the Netherlands included looking at removal through five different water treatment plants (WTPs) with a variety of sources (KIWA 2007). An ongoing EPA-USGS study is looking at the overall removal of EDCs and PPCPs in 9 surface water WTPs, as well as a more detailed evaluation of individual process removal at 3 WTPs. The USGS also published a study of treatment process effectiveness at removing pharmaceuticals and wastewater contaminants at a single WTP in New Jersey (Stackelberg et al. 2004. Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water treatment plant. *Science of the Total Environment* 329 (99–113)).

**Objectives:**
This project focuses on monitoring source water and finished water for 6 to 10 community water systems (CWSs) to assess source contributions and the efficacy of various treatment processes for removing a variety of EDCs and PPCPs. Specific objectives of the project include the following:

1. Determine the occurrence patterns of a prioritized list of EDCs and PPCPs in source water derived from rivers, reservoirs, and groundwater sources in the U.S.
2. Determine the occurrence and range of concentrations of EDCs and PPCPs in finished drinking waters and compare to the occurrence in the raw waters.
3. To determine the effectiveness of full-scale water treatment plants and processes for removing EDCs and PPCPs looking at both individual compounds and effect-related measurements.
Approach:

The following steps outline the main approach for the project:

1. Review of literature for occurrence of PPCPs in finished drinking waters
2. Determine appropriate analyte list based on literature review
3. Identify full-scale water treatment plants using water supplies with a high potential for EDC and PPCP occurrence and using a variety of water treatment processes (range of conventional, physical/chemical including GAC and oxidation, and disinfectant treatment processes).
4. Conduct sampling programs at each plant across each process for at least a one-year period analyzing for a variety of individual EDCs and PPCPs as well as effect-related measurements
5. Evaluate data in terms of source water quality (including temporal trends), treatment process efficiency, finished water quality, and comparison to results from previous studies

Six to ten (6 – 10) WTPs would be selected to cover a wide range of treatment processes and water supplies. Both surface and ground water treatment facilities will be selected. The focus should be primarily on supplies that are derived from surface waters due to the very large population served from surface-water supplies and the likelihood that EDC contamination is more pervasive in supplies derived from surface waters than ground waters. The sampling locations and events would be selected based on capturing sufficient numbers and concentrations of EDCs and PPCPs to provide meaningful data. Some of the selected source waters should be subject to contamination from wastewater treatment plants, CAFOs, and other likely sources. Samples will be collected seasonally (e.g., wet and dry seasons for variations in flow rates and temperature) for one year to capture seasonal variations in water quality.

In order to best draw direct comparisons between source water and finished water, CWSs should be selected that use a single source water. In addition, WTP residence time should be considered in determining the timing of collecting raw water, samples after each treatment process, and finished water. Design and operating data for each plant also would be collected to allow for comparison of removals between plants and between different individual treatment processes. Study design will include consideration of appropriate methodologies for field sampling methods, analytical methods, and data evaluation.

Recommended Budget: Total project cost is $533,000, including $400,000 in AwwaRF funds.

Recommended Schedule: 30 – 36 months
(Note: we suggest starting this in the 2009 project year to allow results from Phase I of the current USEPA/USGS study to be available)

Partners:
USEPA
USGS
Abstract #19

PROJECT TITLE: Developing Source Water Protection Strategies for Addressing EDCs and PPCPs

Background:
Addressing concerns about EDCs is a significant challenge for water utilities due to the limitations of scientific understanding on the issue (lack of analytical methods, occurrence data, human health effects and risks, sources, etc.) and the slow development of regulatory approaches to guide utilities for appropriate action related to EDCs and PPCPs. Many utilities have to deal with perceived concerns and questions raised by observed environmental impacts (e.g., feminization of male fish) without the benefit of solid scientific data and clear regulatory requirements. This leaves utilities in a difficult position to assure their customers of the safety of their water. As an alternative to waiting for the improvement in science and development of regulations for EDCs, utilities may be able to take a proactive approach by identifying potential sources of high priority chemicals in their watershed and pursuing a dialogue with the owners-operators-regulators of those sources for developing and implementing protection strategies. Research is needed to identify the potential and feasibility of success from such an approach.

Objectives:
The main objective of this project would be to develop an interim strategy for addressing concerns regarding EDCs and PPCPs to be based on national consensus and best professional judgment. A major component of the strategy is developing a relational database that relates significant sources to priority EDCs and PPCPs that they discharge into receiving water bodies. This information can enable utilities to limit their focus on those priority EDCs and PPCPs that are specific to their watershed rather than a comprehensive list of all EDCs and PPCPs. It also can help utilities to identify sources of the EDCs and PPCPs that are found in their raw water, to initiate a dialogue with their owners and stakeholders for implementing effective protective measures at the point of discharge. This strategy would be a cost effective approach for assuring the community that the utility is addressing this concern in a proactive manner based the national best professional judgment.

Approach:
The first step of the approach is to develop a list of priority EDC and PPCP target compounds. This list would be developed based on an extensive literature review such as completed and ongoing AwwaRF projects, available information from EU, and other relevant parameters such as bioaccumulation, and best professional judgment obtained through an expert workshop. The second step would be to identify significant sources of the priority EDCs and PPCPs and potential options for mitigating them. The third step would be to assess the feasibility and cost effectiveness of implementing potential protection measures. This step would require an analysis of the potential barriers/obstacles to implementation, including jurisdictional, regulatory, and resource limitations. Costs and benefits would be estimated for a model watershed based on existing literature data on the specific protection measures, the mitigation of potential adverse health effects, and the multiple benefits that may be achieved as part of a larger source water protection strategy. Because many of the EDCs of
concern are related to agricultural and urban activities (e.g., pesticides, hormones, etc.), many of the measures may be helpful to address other source water quality concerns (e.g., controlling agricultural runoff, agricultural manure and nutrient management, wastewater nutrient load reduction, stormwater treatment for removal of sediment, etc.). The next step of this project would be to pursue a pilot project of using the strategy tool and the feasibility/cost effectiveness data for a feasibility analysis in an actual watershed as a case study, and testing its acceptability by stakeholders. The final step would be to summarize the findings in a final report and make recommendations for protection measures that may be warranted (if any) for various priority EDCs. The final report could serve as a guideline for other utilities.

**Recommended Budget:** $350,000

**Recommended Schedule:** 2 years total:
Step 1 (lit. review/expert workshop for identification of priority EDCs and PPCPs, potential sources and protection measures) - 12 months
Step 2 (feasibility assessment and cost/benefit analysis) – 6 months
Step 3 (final report preparation) – 6 months

**Partners:**
USEPA for developing an interim national strategy
WERF
A water utility for the case study
Abstract #20

**PROJECT TITLE:** Contributions of EDCs and PPCPs to Drinking Water Sources from Point and Non-Point Inputs other than Wastewater Treatment Effluents.

**Background:**
While wastewater treatment plant (WWTP) effluents are recognized as significant sources of EDCs and PPCPs to the aquatic environment, data on surface water contributions from other point and non-point sources are needed to direct source water protection strategies. Existing research has assumed that WWTPs are the most significant sources of EDCs and PPCPs. However, releases of raw sewage from combined sewer overflows (CSOs), leaking septic tanks, CAFOs, industrial discharges, fish hatchery discharges, urban and agricultural runoff, and other point and non-point sources may also be significant sources of EDCs and PPCPs to the aquatic environment. Personal care products, such as nonionic detergents, are used for applications outside of the home (e.g., alkylphenol polyethoxylates used as pesticide adjuvants) and pharmaceuticals are used in animal husbandry. EDCs and PPCPs from animal feeding operations (cattle, swine, poultry, etc.) can enter the environment through onsite as well as offsite pathways. The potential significance of these sources is not well understood. A better understanding of additional point and non-point source contributions is essential for the proper evaluation of source reduction possibilities and opportunities.

**Objectives:**
Evaluate contributions of EDCs and PPCPs from point and non-point sources other than wastewater effluent discharges to surface waters used for drinking water supply.

**Approach:**
1. Review literature and previous occurrence surveys for evidence of sources of EDCs and PPCPs unrelated to wastewater effluent discharges. Provide a comprehensive literature review.
2. Identify point and non-point sources most likely to contribute EDCs and PPCPs to surface water bodies and select multiples sampling sites for each point and non-point source category which are representative of each category.
3. Priority compounds will be determined by literature reviews, knowledge of the chemical characteristics associated with selected sources (i.e. likely environmental behavior, potency etc.), and availability of appropriate analytical methods.
4. Identify hydrologic conditions (seasonal, storm events, base flow) during which the most significant EDC and PPCP contributions are likely to occur for each point and non-point source category.
5. Develop sampling strategy for each source based on identified hydrologic conditions and non-point source pathways (e.g. drainage ditches, tile drains, etc.).
6. Conduct sampling, laboratory analysis, and final reporting.
**Recommended Budget:** $1 million

**Recommended Schedule:** 3 years

**Partners:**
- WERF
- Department of Agriculture
- USGS
- State NPDES regulators
Abstract #21

PROJECT TITLE: National Survey of EDCs in Surface Water Supplies Used by Community Water Systems

Background:
Previous studies of EDCs have focused on source waters that were anticipated to contain EDCs from known or suspected sources, such as wastewater effluent and/or runoff from confined animal feeding operations. Furthermore, many of these studies have monitored for a limited number of EDCs, or for EDCs that may not represent the most important compounds in terms of human-health concerns.

A 2003 AwwaRF project report (#90940F --Assessment of Waters for Estrogenic Activity) reported that the majority (61%) of source waters had measurable estrogenic activity. This study provides important insights that natural and (or) synthetic EDCs, may be present in many source waters nationwide.

As concern about the presence of EDCs in water supplies has increased. For example the Food and Drug Administration used annual sales to estimate use of EE2 in the U.S. and calculated end of pipe concentration of 0.002ppb., There is also a need to monitor for a prioritized list of EDCs in a very large number of CWS supplies, that in aggregate are a representative subset of the Nation’s water supplies. This project focuses on CWS supplies that are derived from surface waters (rivers, reservoirs, canals, etc.) because (1) of the very large population served from surface-water supplies and (2) the likelihood that EDC contamination is more pervasive in supplies derived from surface waters than ground waters.

Objectives:
1. Determine the occurrence of a prioritized list of EDCs including estrogen ethinyl estradiol (EE2), and EDC mixtures in raw water for a nationally representative subset of CWSs that use surface waters.
2. Estimate for the Nation, the number of CWSs and their cumulative population served that contain one or more EDC.
3. To the extent feasible, assess the occurrence findings (i.e. EDC concentrations) in a human-health context by comparison to drinking-water benchmarks.

Approach:
One approach is to utilize the design of the “Random Source-Water Survey” developed previously for the AwwaRF national survey of MTBE and other VOCs in CWS source waters. From this national-scale design, a total of 387 CWSs that use surface waters were randomly selected for monitoring. Weighting factors in the design included both:
1. The percentage of total number of CWSs for five size categories (very small, small, medium, large, and very large) and
2. The total population served by each of the five size categories. Additional details of this design are reported in USGS Open-File Report 01-271 “Design of a National Survey of MTBE and Other VOCs in Drinking-Water Sources”, published in 2001.
It is suggested that this research project not commence until a prioritized list of EDCs is finalized via a separate project, and not until the availability of suitable analytical methods are confirmed.

**Recommended Budget:** This is difficult to determine until the number of analytical methods and their costs are determined for the prioritized EDCs. A preliminary estimate for one analytical schedule, with samples collected and analyzed by a single agency, is $1.3-1.4 million. Therefore, the AwwRF project budget would be approximately $500,000.00 with over half coming from in kind and cash contributions.

**Recommended Schedule:** As noted above this project would commence after the list of prioritized EDCs and analytical method(s) were available. A 3-year research plan might be as follows:
Year-1: Finalize design, establish analytical capability, identify CWSs willing to participate, etc.
Year-2: Complete sampling and lab analyses, start database for concentration data
Year-3: Finalize database, complete QC review, prepare project report, and complete peer reviews

**Partners:**
Metropolitan Water District of Southern California
USGS
Abstract # 22

PROJECT TITLE: EDC and PPCP Sewershed Contributions from Targeted Sources and Evaluation of Cost Effectiveness of Pretreatment Compared to Wastewater Treatment Upgrades

Background:
Existing EDC and PPCP occurrence and removal studies have focused primarily on surface waters and the influents and effluents of wastewater and drinking water treatment plants (WWTPs and DWTPs). A study is needed to further characterize the sources of EDC and PPCP contributions to WWTPs in order to evaluate the cost effectiveness of targeted pretreatment compared to the implementation of major WWTP upgrades.

Objectives:
To evaluate contributions of EDCs and PPCPs from different sewershed inputs and determine the cost effectiveness of targeted pretreatment compared to large scale wastewater treatment plant upgrades.

Approach:
Phase 1: Two or more sewersheds, or sections of sewersheds, will be evaluated which contain predominantly residential inputs along with additional inputs from facilities of interest for their potentially elevated contribution of EDCs and PPCPs. Facilities of interest would include hospitals, retirement and elderly care facilities, and pharmaceutical manufacturing facilities. Samples would be collected at each facility of interest 4 times in one year, once per season, along with an additional sample of the sewershed downstream of the combined sampled inputs. For each sampling event, samples would also be collected at the influent and effluent of the receiving wastewater treatment plant, following the plant retention time, to evaluate removal efficiency for each parameter. If contributions from facilities of interest are proportionately significant, Phase II of the project would begin.

Phase II: A literature review would be conducted to identify one or more treatment technology which has demonstrated successful EDC and PPCP removal. The treatment technology (or technologies) would then be evaluated for the determination of implementation costs and potential removals achievable through pre-treatment at facilities of interest, compared to currently achieved WWTP removal and potential removal following a WWTP upgrade with the selected technology (or technologies).

Recommended Budget: $1.2 million

Recommended Schedule:
Year 1: Selection of two or more sewersheds (or sewershed sections) and one or more treatment technology for the pretreatment assessment, sampling plan development, finalization of list of targeted compounds
Year 2: Sample collection and sample processing
Year 3: Data analysis, loading calculations, and cost benefit analysis comparing targeted pretreatment with WWTP upgrade

Partners:
WERF
Hospitals
Pharmaceutical Manufacturers
Sewer Authorities
Abstract #23

PROJECT TITLE: Occurrence, Fate and Transport of EDCs and PPCPs in the Distribution System

Background:
Results of published studies indicate evidence of possible occurrence of byproducts associated with oxidation (e.g., ozonation, UV/peroxide, and chlorination) of EDCs and PPCPs. A separate proposed study aims to identify the occurrence of priority EDCs and PPCPs in the treated water. Additional information is needed regarding the occurrence of persistent transformation products in addition to priority EDCs and PPCPs. In addition, certain piping materials (e.g., sealants) potentially could contribute EDCs in the distributed water. If the original EDCs and PPCPs and/or transformation products are discharged with the treated water into the distribution, then more information is needed regarding the characteristics of residual EDCs, PPCPs and transformation products in the treated water and the subsequent fate, transport and transformation of these compounds in the distribution system.

Objectives:
The objective of this project is to evaluate the occurrence, fate and transport of priority EDCs and PPCPs and transformation products in drinking water distribution systems. This project would be based on findings of the occurrence study that characterizes EDCs and PPCPs discharged with treated water. This study would also be predicated on the availability of data regarding transformation products entering the distribution system. Conduct sampling of tap water at representative locations and correlate to treatment processes. This study would provide needed information for drinking water customers.

Approach:
- Determine analytes, sample pool (one-time sampling)
- Workshop
- Sample product water
- Sample end users
- Analyze samples
- Evaluate persistent EDCs and PPCPs and possible new and transformed products.
- Write final report

Recommended Budget: $350,000 (AwwaRF contribution)

Recommended Schedule: 18 months

Partners:
USEPA
Water utilities
PROJECT TITLE: Linking and validating bioassays for exposure, effect and public perception.

Background:

The use of bioassays for screening of potential hormonal activities in the water cycle, for example for estrogens, is a cost-effective way to evaluate the water quality in different (drinking) water sources, during treatment, etc., additionally to chemical analyses of target substances (natural or synthetic hormones and endocrine disrupting chemicals). For many individual anthropogenic substances or degradation products hormonal activities are still not known and analytical methods are not available. Additionally to the screening of estrogenicity there is also a need for screening techniques for other hormones or EDCs like androgens, progestogens, thyroids and corticosteroids.

Appropriate design and implementation of bioassays by design will facilitate assessment of reduced risk following treatment. However, depending on treatment process utilized, it is imperative to design a complementary array of assays capable of identifying specific toxicities from each component of the treatment process. This may include assessment for presence/reduction of parent compound, development of intermediates and metabolites, and formation of toxic/reactive reagents from the treatment process itself.

For this purpose it is thus imperative to employ a complementary array of assays capable of: 1. determining removal of parent estrogenic contaminant form drinking water; 2. identifying formation of degradation intermediates or metabolites; and 3. assessing the formation of toxic/reactive reagents during the treatment process.

The choice and development of appropriate test systems used to characterize endocrine disrupting compounds (EDC) is highly variable and at present there are no standardized test guidelines in place for the detection of EDC’s. Due to the complexity of the endocrine system and the number of potential mechanistic targets, a multi-component approach involving a complementary array of assays is necessary. The design of these assays as a testing regime is that a combined battery of specific bioassays will provide an efficient, inexpensive screening procedure, which will provide qualitative and quantitative information on the potential toxicity associated with the treatment process. Additionally no set of assays for determination of EDC activity in drinking water has been established. Thus a goal of these testing design is to develop a sensitive and reliable testing strategy that will consistently and accuracy identify the presence of EDC’s in drinking water treatment processes and relate these data to human and environmental health effects.

A multi-component testing approach incorporating both in-vitro and in vivo bioassays and effects data for the analysis of endocrine mediated activity/toxicity will be developed. The approach will encompass multiple levels of biological complexity and offer the distinct advantage of both in vitro and in vivo testing. Individual assays differ in respect to mechanism and functionality, providing a breadth of information on EDC activity with regard to differing mechanisms of action. The goal of this approach is to develop a compendium of assay that can be used as a tire one screening for waters for
prioritization to chemical analysis, Secondly to develop the link between mechanistic based in vitro assays and biological responses that are suitable for public scrutiny and perception for example is my drinking water feminizing fish- is that going to happen to me?

**Objectives:**
Provide an efficient, inexpensive screening procedure, which will provide qualitative and quantitative information on the potential toxicity associated with the treatment process.

**Approach:**
1. Identify particular compounds desired for comparison in in vitro and in vivo assays for various EDCs classes.
2. In vitro assays – Identify and select established bioassays for Estrogens, Androgens, Progestins, Glucocorticoids, Thyroid hormones and other(s).
3. In vivo assays – Identify and select established bioassays for Estrogens, Androgens, Progestins, Glucocorticoids, Thyroid hormones and other(s). Whole animal assays for fish, invertebrates, Established biomarkers in organism(s) of choice. Evaluate Genomic/Proteomic approach appropriate for particular compound or effect.
4. Validation of response predictions between in vivo and in vitro assays.
5. Provide data for use as training sets in Computational Methods project (see #46)

**Recommended Budget:** $450,000 (2008-2010)

**Recommended Schedule:** 36 months
Abstract #25

**PROJECT TITLE:** Handbook of Screening Values for Unregulated Contaminants, such as Endocrine Active Chemicals, Pharmaceuticals and Personal Care Product Ingredients in Water

**Background:**
Drinking water sources inevitably contain low concentrations of a wide variety of chemicals that are common in commerce. At present major concerns focus on endocrine disrupting chemicals (EDCs), pharmaceutical agents (PHARMs), and ingredients of personal care products (PCPs). But there are a variety of other chemicals in that are unregulated and could occur in sources for drinking water. Some of the chemicals have very limited data while others are very data rich. In either case the process of MCL development is very unwieldy and exorbitantly expensive. The Threshold of Toxicological Concern (TTC) approach utilized by the USFDA to deal with indirect additives to food provides a methodology that can be used to identify those compounds that require further research, but at the same time provide levels in drinking water that would be protective of public health for most of the chemicals. To differentiate these numbers from formal MCLs, they will be referred to as reference health values or screening values, depending on the methodology used to derive them.

It is important that these values be generated by an appropriate authority that is respected which has no vested interest in the levels adopted. As much of the concern centers around compounds that turn up in domestic wastewater and indirect potable reuse of such waters continues to expand around the world, it is suggested that this project be conducted by the World Health Organization, or some other respected agency. These working groups provide a forum for identifying concerns and formally developing guidance methodology.

The methodology of choosing and developing screening values (called ADIs in 3085) that allow for a quick, reliable and health-based determination for PCPs and EDCs has been developed in AWWARF project # 3085. The method used is a standard, US government, based risk assessment approach, initially developed by the National Research Council in 1985. This method developed in 3085 has been reviewed by the experts in the project’s PAC, presented to the California Department of Health Services, and is planned for another level of review with state and federal agencies for further vetting. A second project directed at the development of screening values (as opposed to ADIs) has been recently funded (WRF-05-005). This should provide a series of case studies that will provide preliminary validation for applying the TTC concept to contaminants of drinking water. The TTC provides for the identification of default values for chemicals with limited toxicological data. It is not intended that these screening values be used for the purpose of establishing MCLs, but to provide a prioritization tool for determining which chemicals require better toxicological characterization.

**Objectives:**
The objective is to develop values that can be used by the water industry for a wide variety of chemicals that occur in drinking water or drinking water source waters
that will ensure public health protection. It is essential that this project work towards the validation of the TTC approach for developing default screening values. Prior work (e.g. AwwaRF 3085 and WRF 05-005) provide the data for validating the TTC approach.

**Approach:**

- Develop reference health values using traditional risk assessment methods for a range of PPCPS and EDCs that have been detected in the environment
- Develop methods framework to calculate conservative screening values for unregulated contaminants with incomplete data sets
- Calculate screening values for chemicals with complete data sets as validation case studies
- Work with diverse stakeholders in workshops, ILSI-HESI, or other venues to gain acceptance for the approach
- Have approach reviewed by a third party NGO, such as WHO, to provide globals acceptance for the process
- Create screening values for additional unregulated chemicals
- Create a handbook for use by water utilities to address questions related to drinking water quality

**Recommended Budget:** It is anticipated that the total cost of the project would be between $300 and 400K. The effort would require several meetings of stakeholders. It is suggested that AwwaRF identify funding partners, such WRF, WERF, and various utilities.

**Recommended Schedule:** 3 years.
Abstract #26

PROJECT TITLE: Computational Toxicology CRADA with NHEERL

Background:
NHEERL has established a program in computational toxicology. They are looking for partners to support that activity. Much of the work will focus on the characterization of gene expression and protein expression changes that occur in response to various environmental comments. A large part of this effort will initially be directed at understanding responses in in vitro systems. These are ideal systems for identifying chemicals that are endocrine active compounds. Eventually, they will be utilized to begin risk assessment on chemicals within these groups as a result of the EDSTAC process. Participation of AwwaRF in this project could steer this program to chemicals of interest to the drinking water community.

Objectives:
1. To influence chemical selection for testing within the NHEERL computational toxicology program to chemicals of interest to AwwaRF and its constituent utilities.
2. Contribute to data collection for the computational toxicology effort with an in vitro/in vivo (i.e. fish) screening system of interest to AwwaRF where the data can eventually be evaluated against reference data (both in vivo and in vitro data) collected for the computational program. (separate project proposal #15)

Approach:
AwwaRF should consider contributing the EPA computational toxicology effort through a CRADA that has recently been advertised. It is suggested that this project be contributed to at two levels. The first would be to assist the industry to identify compounds that may be uniquely of concern to AwwaRF (i.e. not on compounds for which EPA is mandated to collect data from industry under TSCA or FIFRA) because of occurrence in drinking water and the second to assist in the validation/interpretation of assays used in monitoring of water.

Recommended Budget: Suggest a contribution of 100K per year as long as the relationship proves fruitful AwwaRF. Part of this activity may be directed at attempting to help in the interpretation of data that may be collected in the field with in vitro screening methods (see project description).

Recommended Schedule: Ongoing as long as it proves to be a fruitful for AwwaRF.
PROJECT TITLE: Method Validation by interlaboratory Comparison for Priority Pharmaceuticals (GWRC)

Background:
Analytical chemistry plays a key role in the detection of emerging contaminants such as PhACs. Through the continuing advancement in analytical techniques, PhACs can now be detected and reported at part-per-trillion (ppt) levels in water and, as a result, have gathered attention from scientists as well as the general public. The literature on PhACs has been growing at a fast pace, with different types of analytical methods employed that include gas chromatography coupled with mass spectrometry (GC/MS) and liquid chromatography with mass spectrometry (LC/MS). Tandem mass spectrometry is increasingly used to improve sensitivity and selectivity. However, no standardized and approved analytical methods exist. Subsequently, inter-laboratory results and costs may vary widely due to different laboratory practices. This is especially true when LC/MS is used without isotope dilution, where matrix effects can cause either signal suppression or enhancement and render the results semi-quantitative at best. Standardization of existing analytical methods is needed to ensure high quality data from each laboratory involved in the analysis, and will aid water agencies and regulators to better monitor the occurrence of PhACs.

Objectives:
To evaluate and standardize analytical methods for PhACs to provide low-ppt detection levels in water at lower cost and with readily available technologies. To demonstrate comparability between alternative methods.

Approach:
The Project Scope will include the following:
1. Review of literature on existing method for analysis of P/PCPs
2. Selection of potential methods (3 to 4) for further evaluation based on following criteria: precision, accuracy, and recovery of each method.
3. Obtain isotopically-labeled standards and synthesize non commercially available ones
4. Preservation studies; QA/QC concerns for sample preparation
5. Inter-laboratory round-robin tests
   a. surface water matrix
   b. treated wastewater matrix
6. development of guidelines/recommendation for best analytical practices
   a. sample collection, storage and preservation
   b. extraction/concentration
   c. quantitation
   d. isotope dilution method for LC/MS; may need to work with isotope laboratories to make labeled standards more available and at lower costs
   e. GC/MS; may need derivatization step for some analytes
Recommended Budget: AwwaRF cash: $350K. Total project value: $ 750

Recommended Schedule: 3 years
PROJECT TITLE: Broad spectrum screening of PPCPs and EDC’s in waters using novel techniques

Background:
Since the 1970s, GC/MS and HPLC-low resolution MS (MS) are the methods of choice for identification of PPCPs and EDs. Although GC/MS allows the identification of unknowns, only a maximum of 1000 compounds can be separated during a single run, which is insufficient to resolve the thousands of PPCPs and EDCs available on the market and hence likely to be present in waters. HPLC/MS techniques have been solely used for target analysis of a predefined list of analytes. It is therefore likely that many relevant PPCPs and EDCs have been ignored by these traditional approaches.

New generations of instruments or analytical techniques recently made available seem to have the capability to separate a much higher number of analytes in a single analysis with minimal sample preparation. This enhanced resolution allows the identification of compounds that were previously coeluted or buried in the background noise. Furthermore, the resolution of new generations of MS instruments coupled with HPLC, together with their ability to acquire full mass MS/MS spectra and daughter ion spectra simultaneously, makes it possible to identify unknown polar compounds by HPLC- high resolution MS.

Objectives:
The objective of this research is to apply novel techniques for broad, rapid screening of PPCPs and EDCs in order to identify new compounds outside the priority ones.

Approach:
1. Identify a GC based technique with the potential to separate up to 10,000 non polar and semi-polar compounds in the same chromatographic run.
2. Identify an HPLC-high resolution MS approach for the identification of non target polar drugs and metabolites
3. Apply above approaches to a wide range of water matrices including wastewaters, source waters and tap waters for the identification of a broad range of PPCPs and EDCs

Recommended Budget: $200,000 X 2 (AWWARF)  
$400,000 X 2 (Total)

Recommended Schedule: 2009-2010
Sponsors Research
Develops Knowledge
Promotes Collaboration